SPD-765-01

A SYNTHESIS OF AALC PROGRAM AIR CUSHION VEHICLE SEAKEEPING DATA

ADA040122

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

DEPARTMENT OF THE NAVY DTNSRDC

A SYNTHESIS OF AALC PROGRAM

AIR CUSHION VEHICLE SEAKEEPING DATA

by

ALVIN GERSTEN

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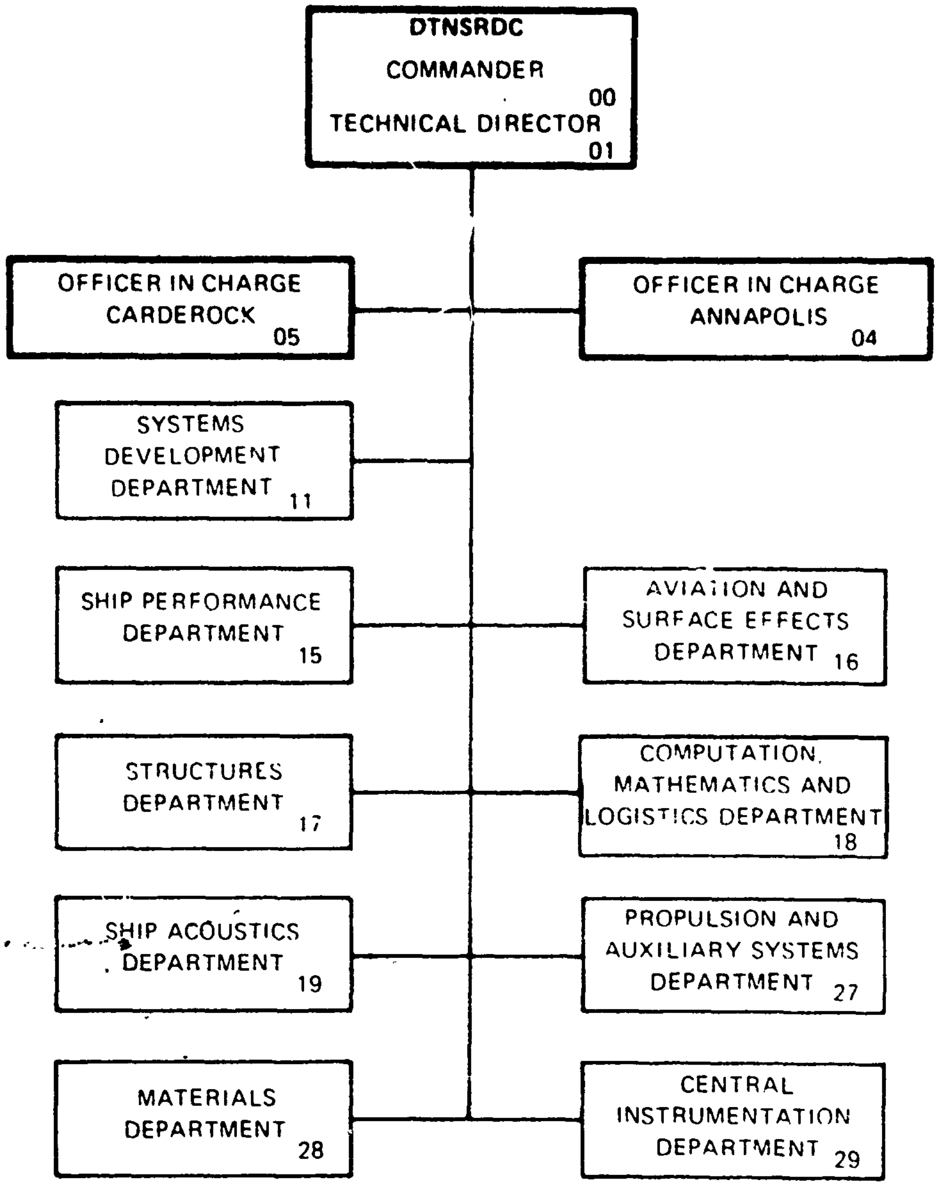
SHIP PERFORMANCE DEPARTMENT

DEPARTMENTAL REPORT

APRIL 1977

SPD-765-01

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
SPD-765-01

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
A SYNTHESIS OF AALC PROGRAM AIR CUSHION VEHICLE SEAKEEPING DATA

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Alvin Gersten

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Ship Performance Department
David W. Taylor Naval Ship R & D Center
Bethesda, Maryland 20084

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
Task Area SAW 02001
Element Number 14124
Work Unit Number 1-1180-004-36

11. CONTROLLING OFFICE NAME AND ADDRESS
David W. Taylor Naval Ship R & D Center
Systems Development Department
Bethesda, Maryland 20084

12. REPORT DATE
April 1977

13. NUMBER OF PAGES
70

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS (of this report)
Unclassified

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Air Cushion Vehicles; ACV Seaworthiness; ACV Drag; Assault Craft

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Box 20. (Continued)

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ADMINISTRATIVE INFORMATION

This investigation was funded by the Amphibious Assault Landing Craft Program Office, Task Area SAW02001 Element Number 14174. It is identified as Work Unit Number 1-1180-004-35.

INTRODUCTION

Several different types of model experiments have been conducted on the Aerojet General Corporation (AGC) and Bell Aerospace Company (BAC) designs for the Amphibious Assault Landing Craft Program's (AALC) JEFF craft. However, published performance comparisons for these air cushion vehicles (ACV's) have not been provided heretofore. A synthesis of the data was needed since the available results are dispersed among many documents, making it difficult to assess the relative merits of the two designs. The initial experiments were generally carried out for the prime contractors. These were often followed by experiments sponsored directly by the AALC Program Office to validate and supplement the contractors' findings.

As background, it should be noted that during the preliminary design phase, specifications designated this vehicle concept as a C150-50 since it was to have air cushion support, a nominal payload of 150,000 lb (68,040 kg) and a nominal speed in Sea State 2 of 50 knots. As experiments and further analyses were carried out, the preliminary designs were established, and the craft were re-designated as JEFF configurations; this constituted the start of the detailed design phase.

This report presents comparisons of vehicle motions, accelerations and drag during operation in waves (both deep water waves and surf) for the AGC and BAC configurations. Some calm water drag data are also presented. Results obtained from different sources for the same configuration as well as data for a particular contractor's design at different stages of its development are discussed. Although most of the predicted responses were derived from model experiments -- motions, speeds, wave heights, etc. will be given full scale as they were extracted from the documents cited. Reference is frequently made in the text and figures to the particular model used in the program of experiments.

EVOLUTION OF MODEL DESIGNS

Early experiments were carried out by AGC at their facilities on their Models 104 and 105 as part of the preliminary design phase (Phase 1) of the C150-50 program: Model 104 had a multi-cell and peripheral skirt cushion system (8 circular tapered cells) and Model 105 had 45 tapered cells located around the periphery of the hull. Experiments on Models 104 and 105 were also conducted at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) under AALC Program Office sponsorship. Towards the end of the preliminary design period, a 1/16-scale "C150-50 Verification Model" was manufactured. This represented the final configuration of Phase I: the skirt system consisted of a peripheral loop supporting 60 peripheral cells; the loop was divided into four quadrants by a transverse diphragm amidships, and one on the centerline oriented fore and aft. Most of the findings from these initial experiments were reported in an AGC preliminary report.

In 1971, subsequent to starting the detailed design phase (Phase 2), AGC constructed a 7/100-scale model of the now-designated JEFF (A) and incorporated then-current design modifications. The principal changes from the 1/16-scale verification model which preceded it were in the lift system, including the skirt configuration. The skirt bow loops and cells were modified: for example, the loop radius was increased, and the upper attachment line raised. Alterations were also made to increase the tension force on the bow cells in the forward direction and to reduce their tendency to be deformed. The lower edge of each of the bow cells was moved forward to give a greater cell area and to retain the original cushion length since the craft overall length was reduced slightly. The bow corner cells were also modified so that they were all of one common design; a similar step was taken with the stern corner cells. The side cells remained the same, but they were repositioned longitudinally to conform to the frame spacing of the then current "Reference Configuration". The combined effect of these changes on the cushion planform was small, but the total number of cells was increased from 60 to 62. Although the lift fans and drive system were the same as on the 1/16-scale verification model, the location of the fans was altered.

A new 7/100-scale model was built in 1972. It incorporated an updated set of lift fans mounted on the latest craft configuration. The previous fans had a 3.80 in. (9.7 cm) diameter, whereas the revision resulted in a smaller 3.72 in. (9.45 cm) diameter and a higher operating speed to more closely represent full scale performance. Several skirt configurations--all of the loop/pericell concept--were provided for evaluation on the model.

During the preliminary design phase, BAC also carried out model experiments, and they designated as B-17 their 1/12-scale dynamic model representing the C150-50. A bag-and-finger skirt system was installed. After entering the detailed design stage, the B-17 model was altered to represent the newly designated JEFF (B) and re-labelled B-17(A). The chief modification was replacement of the stern and transverse stability seals with new seals incorporating acute angle closed fingers. The original seals utilized conventional right angle closed fingers. In addition, several structural modifications were made.

Subsequently BAC revised their design again and developed a Design Engineering Review (DER) JEFF (B) model which employed 60 percent fingers with a height to pitch ratio of 1.5 instead of the original 50 percent fingers with a height to pitch ratio of 2.0. The cushion area and length to beam ratio also changed slightly in the DER configuration because of the deeper fingers and other modifications to the seal.

DESCRIPTION OF MODELS AND PROTOTYPES

Some pertinent characteristics of the models designed and constructed by the prime contractors in the AALC program are given in Table 1. Also listed are such items as wave conditions and wind speed assumed in determining vehicle performance. For example, if a full scale wind speed of 25 kts is indicated, the effect of wind was included in the drag calculation. The various references used are cited in brackets near the top of each column. In many cases, values for a particular item were not provided in the reference and the space was left blank.

With the exception of AGC Model 104, for which results are not presented in this report* there is a difference of 5.5 percent between

*Experimental data for AGC Model 104 are contained in a DTNSRDC internal document: Gersten, Alvin, "Performance of an Air Cushion Vehicle with a Multi-Cell Skirt in Random Waves", DTNSRDC Report 378-H-13 (March 1971) the heaviest and lightest vehicle weight investigated. There are also small differences in such things as the wave height used to represent a particular sea state, and the longitudinal location of the center of gravity.

A schematic of the multicell skirt on Model 104 is presented in Figure 1. Each two of the eight plenum-type circular cells was fed by one fan. The entire system was fabricated from a thin, flexible fabric. The photograph shows the model during towing tank experiments. AGC Model 105 represented a large step towards the final configuration (see Figure 2) with its peripheral cell design. A cross section through a typical cell is shown in Figure 3, with possible full scale dimensions included for reference.

The 7/100-scale AGC verification model of JEFF (A) can be seen in Figure 4 with the basic skirt installed. The number of cells is 62 as compared to 45 on Model 105. Another skirt system installed on the 7/100-scale model was made up of 124 half-width cells; this version is depicted in Figure 5. A drawing of what is essentially the latest version of the JEFF (A) prototype is given in Figure 6. The similarity between its skirt and the basic model skirt of Figure 4 is evident.

Figure 7 is a drawing of the BAC B-17 model. The fixed stern propulsors and rotatable bow thrusters were included to reproduce topside features. The C150-50 prototype which the model represents is shown in Figure 8, where the bag-and-finger skirt (seals) can be seen. Rudders and ramps required on the prototype were also provided on the model.

COMPARATIVE PRESENTATION OF RESULTS

DRAG IN CALM WATER

In Figure 9, a comparison is made between calm water drag for AGC and BAC C150-50 designs. Both sets of results are based on experiments conducted at DTNSRDC.* The model data were Froude scaled directly to obtain full scale values. The AGC design exhibits much greater drag in this plot--particularly at speeds above hump--than the BAC design does. The ratio of maximum values is 1.4, with the higher AGC curve peaking at 20 kts and the BAC curve peaking at 16 kts. There were some differences in vehicle conditions which could be partially responsible for the AGC C150-50 exhibiting greater drag; for example, Table 1 shows that the weight of the AGC model was 3.6 percent greater than that of the BAC model.

The AGC C150-50 model underwent drag experiments at the Davidson Laboratory (DL) prior to those conducted at DTNSRDC. Figure 10 compares the DTNSRDC curve from Figure 9 with the DL results which were extracted from the AGC Preliminary Design Summary Report (PDSR).[1]** The difference is quite large, with DL predicting much lower drag.

AGC, at the request of the AALC Program Office, investigated the discrepancy, but could not arrive at a concrete cause. In Reference 2 they conclude that there is no simple, single, nor complete explanation

* These results are reported in the following internal documents: Kallio, James A., "Seaworthiness Characteristics of a AALC C150-50 Verification Model Part II: Bell Aerospace Company Design", DTNSRDC Report 378-H-11 (February 1971); and Kallio, James A., "Seaworthiness Characteristics of a AALC C150-50 Verification Model Part I: Aerojet-General Corporation Design" DTNSRDC Report 378-H-10 (February 1971).

**References are listed on page 23.

of the difference in the results. They believe that the major variations are due to inconsistencies in model conditions including weight, center of gravity, skirt condition and fan operating speed. Other suggested contributing factors are differences in facilities, rigging and instrumentation including hydrodynamic channel width and water depth effect, aerodynamic interference effects and methods of calibration.

It should be noted that the PDSR (Reference 1) indicates a model weight for the DL experiments which is slightly greater than the DTNSRDC value {equivalent full scale magnitude 338,330 lb (153,466 kg) at DL compared to 337,000 lb (152,863 kg) at DTNSRDC} . In addition, fan rpm was somewhat lower at DL (see Table 1). Both of these facts should, if anything, result in greater drag during the DL experiments -- not the reverse, as actually occurred.

If the lower (DL) curve in Figure 10 is compared to that for the BAC C150-50 in Figure 9, it is found that the AGC design looks better at hump speed and experiences greater drag at cruising speeds. Finally, in a more positive vein, it should be stated that DL and DTNSRDC drag results for the Sea State 2 design condition -- which are discussed later in this report -- are in better agreement than the calm water drag.

DRAG IN A SEAWAY

Since the AALC craft will be operating in waves of at least moderate severity most of the time, it is important to compare the resistance in a seaway of the AGC and BAC designs.

Such a comparison is made for the early C150-50 configurations in Figure 11. The calm water drag curves are also provided to establish a frame of reference. The BAC design exhibits more favorable drag performance in Sea States 2, 3, and 4 just as it does in calm water. The difference is so pronounced that drag for the BAC craft in Sea State 3 is comparable to that of the AGC craft in calm water. However, it should be noted that the difference in drag in a seaway is primarily a reflection of the difference in calm water drag; the drag increase due to wave action is roughly the same for both craft.

After several design changes from the inital C150-50 (as discussed previously) each contractor arrived at a JEFF boat concept at the time of the DER. Full scale drag predictions for operation in waves were made based on towing tank and wind tunnel experiments.[3,4] The results are presented in Figure 12, and pertain to operation in Sea States 2 and 3 in a 25 kt headwind.* The difference in resistance is not as great as indicated in Figure 11; however, JEFF (A) does generally perform worse than JEFF (B) over much of the post-hump speed range. An exception occurs in Sea State 2 above 40 kts. The JEFF (B) drag characteristic in Figure 12 is comparable to that of the BAC C150-50 in Figure 11, but the AGC C150-50 drag is significantly greater than that of JEFF (A)--particularly in Sea State 3.

The JEFF (A) craft represented in Figure 12 is slightly heavier than its JEFF (B) counterpart {333,000 lb (151,059 kg) compared to

*Details of the wave conditions for each sea state were not provided in the references.

325,000 lb (147,420 kg)}; this would tend to make its drag higher -- although probably not quite as much as shown in the figure.

The JEFF (A) drag data were scaled from the 7/100-scale verification model, and the JEFF (B) data from the B-17A model with a correction for the latter as follows: In Sea State 2 (the design condition) BAC used direct Froude scaling; in sea states greater than 2, BAC -- based on British Hovercraft experience -- assumed that the equivalent full scale wave height was equal to the Froude scaled value times a factor of 1.7

A comparison of drag obtained with the AGC C150-50 verification model by AGC and presented in its PDSR and also obtained by DTNSRDC* is given in Figure 13. The AGC PDSR Sea State 2 results are shown for two effective longitudinal CG locations (trim moments); the more forward CG yields a more complex hump drag characteristic. In Sea State 2 the DTNSRDC data predicts greater drag while in Sea State 4 the reverse is true. The greatest difference between the two predictions is about 14.7 percent and occurs at 20 kts in Sea State 4.

The AGC DER Sea State 2 drag curve from Figure 12 is repeated in Figure 14 along with DTNSRDC data from calm water and wave experiments taken from Figures 10 and 11, respectively. It should be noted that the DER data were obtained with a 7/100-scale model of the JEFF (A) which incorporated refinements of the earlier 1/16-scale C150-50 model employed at DTNSRDC. The DTNSRDC calm water drag curve indicates more or the same drag than the Sea State 2 curve from the DER up to a speed of roughly 45 kts. In addition, the DTNSRDC data points for Sea State

*See first footnote on page 7.

2 represent much greater drag -- particularly at 40 kts -- than the DER Sea State 2 results. This is true even though the DER prediction includes the effect of a 25 kt headwind and the DTNSRDC prediction assumes zero wind speed. Presumably this is due in large measure to the improved design of the updated 7/100-scale model compared to its predecessor 1/16-scale model. To support this contention it should be pointed out that AGC vehicle drag in Sea State 2 is also lower in the DER (7/100-scale model) than in the PDSR (1/16-scale model). Thus, AGC's own predictions follow the same trends demonstrated in Figure 14.

As a "point of information", it is mentioned that Reference 5 contains model scale data for an earlier configured AGC 7/100-scale model than is shown in prototype form in Figure 8 (see section on model evolution).

A typical variation of drag with sea state which was taken from Reference 6 can be seen in Figure 15. In this case, there is a greater increase in drag when going from Sea State 2 to Sea State 3, than when going from calm water to Sea State 2. In all sea states, the primary and secondary drag humps occur at about the same speed.

Figure 16 has been included to show that the BAC drag prediction for operation in Sea States 2 and 3 was not changed significantly between October 1972 and January 1975. As noted in an informal communication from BAC to DTNSRDC*, the 25 kt headwind condition imposed by the Navy is severe since it is normally associated with fully developed seas of much greater severity than Sea State 2 or 3--probably

*Letter from C.A. Pierson BAC to B. Benson DTNSRDC (Code 1183), CAP:bmh, dated 20 January 1975.

more like Sea State 6. The solid curves in Figure 16 come from the document cited in the footnote on page 11, and the broken curves come from Reference 4.

BAC used two different methods to scale up model drag to prototype values. Although one method was rather complicated[4], and the other used uncorrected model data Froude-scaled to the prototype JEFF (B)[7], the results are not much different. In Figure 17 we see drag curves for Sea State 2 obtained by the two methods. The solid curve was derived as follows:

a. Model drag was Froude-scaled to full-scale JEFF (B) values.

b. Corrections were applied to account for variances of model geometry from scale and "other factors".

c. Seal drag component was reduced by 10 percent in Sea State 2 and above.

d. Correction was applied to account for stability seal gap since the design $p_{bag}/p_{cushion}$ and stability seal height couldn't be established on the model.

e. Aerodynamic drag was reduced for the prototype since its frontal area is a little smaller than the model value scaled up. The broken curve, on the other hand, results from direct Froude scaling. Nevertheless, the difference in the two curves is negligible, except possibly above 55 kts.

In a headwind, vehicle drag normally increases as the wind speed increases. Figure 18 gives a representative picture of this relationship. The full scale predictions were taken from Reference 8. It is assumed in the figure that sea state remains constant even though the wind has picked up. As the wind speed is increased, the craft forward speed hump drag does not change since the hump condition is a hydrodynamic phenomenon not an aerodynamic one; therefore, the curves appear nested. There should be a greater increase in drag for equal increases in wind speed because the aerodynamic drag increases as the square of the wind speed. This effect is evident at post-hump speeds.

MOTIONS AND ACCELERATIONS IN A SEAWAY

Trim and Static Heave

The severity of the waves in which an ACV operates affects its static heave (squat) and mean trim. Figure 19 shows the variation of static heave and trim with sea state for head sea operation. The data were scaled up from Reference 6 where they were presented for the AGC 7/100-scale model with the current JEFF (A) skirt configuration. At cruising speeds the craft has a shallow immersion compared to the hump condition; however, immersion does increase with increased sea state. Bow up trim is also small at cruising speeds, but it decreases with sea state.

Dynamic Responses in Deep Water

Significant (average of the highest one-third) pitch for the AGC and BAC C150-50 designs is compared in Figure 20. The data are presented as a function of sea state and speed, and were scaled up from the pre-DER, 1/16-scale, AGC model and the 1/12-scale, BAC, B-17 model.* According to these results the BAC C150-50 experiences a little less pitch in all sea states considered in the 20 to 40 kt speed range.

*See first footnote on page 7.

This statement must be qualified by the fact that although the significant wave height for a given sea state was approximately the same for both series of model experiments, the distribution of wave energy was not necessarily the same. This can be seen in Figure 21 and should be considered when comparing vehicle responses. For example, in Figure 21a at a frequency of 2.5 rad/sec the spectrum for the AGC model experiment has maximum energy whereas the BAC spectrum reaches a minimum point with much less energy. This difference could have a significant effect on comparative model motions because of different matching of maximum wave energy and pitch natural frequency.

Figure 22 compares heave for the two C150-50 designs in different sea states. The difference in heave is small in spite of the more pronounced differences in the wave spectra.

Histograms of pitch and heave for the C150-50 configuration are presented in Figure 23. Differences between the AGC and BAC versions are not large -- just as was found true when comparing significant values in Figures 20 and 22. The basic shape of the histograms is the same for both craft in both sea states. For example, in all cases the modal value is found in the second smallest class interval.

In order to demonstrate how pitch response was altered in the design evolution from BAC C150-50 (B-17 model) to JEFF (B) (B-17A model), Figure 24 was prepared. Although Reference 9 -- the source of data for the JEFF (B) -- does not give information on the wave spectral shape employed, it is known that the wave heights were a little higher for these experiments than for the C150-50 experiments. For example, average of the highest one-tenth full scale wave heights were as follows:

	C150-50	JEFF (B)
Sea State 2	2.6 ft	2.8 ft
Sea State 3	4.7	5.8
Sea State 4	8.2	8.7

Pitch of the C150-50 was greater than that of the JEFF (B) in Sea State 2, and appreciably less in Sea State 3 and in Sea State 4 above hump speed. The degree to which C150-50 pitch is lower at post-hump speed in the two higher sea states appears to be greater than can be attributed to the difference in wave height.

In the next section of this report we will discuss characteristic motions of the C150-50 configurations as represented by response amplitude operators (RAO's) for head sea operation. RAO's characterize craft behavior normalized to the wave excitation.

A comparison of pitch RAO's for the AGC and BAC craft is given in Figure 25. As noted, they pertain to operation at 40 kts and were derived from experiments in Sea State 2. There is no substantial difference in the two RAO's -- except perhaps at frequencies above about 4 rad/sec. Pitch RAO's for a speed of 30 kts, obtained from experiments in Sea States 3 and 4, are presented in Figure 26. The AGC design has significantly worse pitch characteristics at this speed then its BAC counterpart: the maximum RAO value is 9.0 for the AGC configuration and 6.0 for the BAC one. The RAO's derived from each sea state for a particular craft are about the same; this fact provides some evidence for pitch linearity. The frequency at which maximum response occurs indicates that both designs have a natural pitch period, T , of roughly 2.2 sec. By comparing Figures 26a and 26b with

Figure 25 it can be seen that pitch of the C150-50 will tend to be greater at 30 knots than at 40 knots.

In Figure 27, C150-50 heave RAO's for a prototype speed of 40 kts are shown. Just as for pitch, there is not much difference in heave response characteristics at this speed. Heave RAO's for 30 kts are given in Figure 28: the curves derived from experiments in Sea State 3 (Figure 28a) indicate a more favorable performance (lower peak value) for the AGC design -- but the superiority is not in evidence for all frequencies. The curves resulting from Sea State 4 experiments (Figure 28b) do not favor one craft -- there is merely a small shift in the frequency of maximum response. If one compares the RAO's associated with Sea State 3 and Sea State 4 operation, it will be found that the AGC C150-50 decreases its frequency for peak response as sea state increases, and increases the magnitude of the peak (from 1.2 to 1.5). The BAC C150-50 on the other hand, increases its frequency for peak response as the seas get more severe, but retains the same peak magnitude. Because the frequency for maximum heave differs so much from one sea state to the other, it is difficult to specify a natural heave period.

The AGC C150-50 pitch and heave RAO's shown previously in Figures 25 and 27, respectively, were obtained foom experiments carried out at DTNSRDC. They are repeated again in Figure 29, and compared with results obtained at the Davidson Laboratory[10] at a slightly lower speed. The heave results agree very well which is what one would expect for a small difference in speed. The pitch RAO's on the other hand, do not agree very well. To a large extent this could be reconciled by a shift of the Davidson Laboratory data points to higher frequency. However, the maximum data point is higher than the peak of the curve (7.0 compared to 5.5).

Bow acceleration RAO's for the C150-50 designs are compared in Figures 30 and 31. The rigid body accelerations considered here are associated with pitch and heave motions. Figure 30 indicates that at 40 kts both craft have similar normalized bow acceleration response; however, the AGC curve--whose high frequency response is not completely defined--does reach a greater maximum value.

The results for a speed of 30 kts obtained from experiments in Sea State 3 (Figure 31a), show that the AGC craft experiences appreciably larger accelerations than the BAC craft--although the shape of the curves is similar. A distinct peak occurs in both cases at a frequency of approximately 3.5 rad/sec. There is a clear-cut difference in the AGC curve obtained from Sea State 4 experiments (Figure 31b), and the acceleration levels are more in line with those of BAC's design (which has essentially the same RAO as in Figure 31a). Details of the two curves in Figure 31b are different, however.

Maximum bow impact acceleration for the C150-50 ACV's is shown in Figure 32. The accelerations are less severe for the BAC vehicle in Sea States 2 and 3; they are the same for both craft in Sea State 4. The impact accelerations are more severe than those caused by motions, and reach approximately 7.0g's in Sea State 4.

Survivability of the JEFF (A) and JEFF (B) when hullborne in moderately severe seas was examined at DTNSRDC.* Typical wave spectra from both experiments are presented in Figure 33: in this particular case the significant wave height was slightly larger for the JEFF (A) experiments, but the spectra are very similar. Table 2 compares the significant double amplitude of motions and accelerations at zero speed for the two designs. Roll is important to consider because there is a possibility--albeit remote--of the craft capsizing, particularly if it is damaged and is listing. It can be seen in Table 2 that list was established on the model for some runs; this was done by shifting ballast. The intent was to simulate a CG shift due to movement of cargo, or intake of water due to a hull penetration. Roll is greater for the JEFF (B) in all cases tabulated but the last, where both craft are found to roll about the same. In beam seas, with a 3.5 deg list from the sea, JEFF (B) has a significant roll 2.6 deg greater than that of JEFF (A). Pitch is also greater for JEFF (B) for all heading and list conditions. Heave acceleration is essentially the same for the two ACV's.

MOTIONS AND ACCELERATIONS IN SURF

Experiments were carried out in surf with the C150-50 models at Hydronautics Inc., and the results are contained in References 11 and

* Detailed discussion of the results can be found in the following internal documents: Conrad, R.E., "Intact and Damaged Stability Behavior of the JEFF (A) Design of an AALC Air Cushion Vehicle in a Sea State 5", DTNSRDC Evaluation Report 467-H-03 (August 1972); and Conrad, R.E., "Intact and Damaged Stability Behavior of the JEFF (B) Design of an AALC Air Cushion Vehicle in a Sea State 5", DTNSRDC Evaluation Report 467-H-02 (August 1972).

12. To create the surf zone, a beach was set up at one end of the tank and regular waves were generated from the other end and allowed to propagate over the beach. A constant ratio of wave height to wave length (1/40) was used for all wave lengths. Wave heights given in subsequent figures are those existing in deep water.

In Figures 34 and 35 maximum pitch and heave while retracting directly through the surf are plotted versus wave height. Figure 34 is for low speed retraction (with slightly different speeds for the two vehicles) and Figure 35 is for relatively high speed (post-hump) retraction. Positive (pitch bow up and heave down) and negative excursions are plotted separately. Maximum positive and negative values do not necessarily occur in the same cycle. The BAC C150-50 generally experiences greater bow up pitch, whereas the AGC C150-50 undergoes greater bow down pitch which is more conducive to slamming and taking of solid water on the deck. Heave for the BAC design is usually greater downward and the AGC configuration experiences greater upward heave. Based on maximum values, there is not a clear-cut superiority of one craft over the other when they are retracting through surf. However, it would have been useful to compare other statistical measures of response such as the average value (which was not given in the references) in order to evaluate their relative performance.

Maximum bow acceleration when retracting through surf is presented in Figure 36 for sub-hump and post-hump speeds. At sub-hump speed the difference in downward acceleration is small, but the AGC values are greater for most wave heights. Upward acceleration is slightly worse for the BAC C150-50, except for a wave height of 10 ft, where the AGC vehicle sustains a maximum upward acceleration of roughly 3.7g's. At the post-hump speed of 24 kts, downward acceleration is frequently greater for the AGC craft while upward acceleration is always greater for the BAC ACV -- particularly for large wave heights.

Beaching was carried out by having the model run at the wave speed and attempting to maintain a steady vehicle position on the breaker being ridden. Maximum pitch while beaching is given in Figure 37. These data are more scattered, making evaluations more difficult than was the case for the retracting runs, because the results depend on where the model rode the incoming wave. As an example, the largest bow down pitch is generally experienced by the AGC C150-50, but on repeat runs the AGC craft also undergoes the smallest maximum bow down pitch. Neither craft demonstrates a consistent tendency to pitch bow up more than the other.

Heave data are also erratic because of the inherently unstable vehicle orientation associated with a beaching operation. The largest maximum heave down is usually associated with the AGC craft, and so too is the smallest value obtained from repeat runs (see Figure 38). Maximum upward heave is very unstable so that each craft experiences both the largest and smallest response at particular wave heights.

Maximum bow acceleration when beaching is compared for the C150-50 configurations in Figure 39. Acceleration downward is greater for the AGC vehicle regardless of wave height. Upward acceleration is mixed, being greater for the AGC craft at small wave heights and greater for the BAC craft in more severe waves.

CONCLUSIONS

Available data -- for the most part pertaining to seakeeping characteristics -- which are useful in comparing the performance of the AALC JEFF craft and their antecedent the C150-50, have been brought together in this report. Comparisons have been made, and the following conclusions reached:

1. The results of experiments conducted at DTNSRDC indicate that the AGC C150-50 has greater drag in a seaway (Sea States 2 to 4) than the BAC C150-50.

2. AGC and BAC drag predictions for the JEFF boats show that at speeds above hump in Sea States 2 and 3, JEFF (A) has slightly greater drag than JEFF (B) up to 40 kts and equal or greater drag than JEFF (B) between 40 and 50 kts.

3. The difference in drag in a seaway obtained from experiments at different facilities, although significant, is not extremely large. For example, the largest difference in AGC C150-50 drag as presented by AGC (based on Davidson Laboratory experiments) and obtained at DTNSRDC is 14.7 percent.

4. The BAC drag prediction for JEFF (B) operation in a seaway was not changed significantly between October 1972 and January 1975.

5. DTNSRDC results show that the BAC C150-50 experiences less pitch than the AGC C150-50 in Sea States 2 to 4 at speeds of 20 to 40 kts. Heave is almost the same for these vehicles. Differences in wave spectral shape which occurred during the course of the model experiments weaken this conclusion to some degree.

6. Pitch response amplitude operators (RAO's), for the two C150-50 craft operating at 40 kts are about the same. At 30 kts, however, the AGC pitch RAO is significantly worse than its BAC counterpart.

7. The natural pitch period of the C150-50 craft is approximately 2.2 sec.

8. Heave RAO's for the C150-50 ACV's are very similar at 40 kts, and both craft are underdamped with a natural period of about 5.7 sec. At a speed of 30 kts the RAO's vary depending on the sea state in which the model was run; there is no clear-cut superiority for either craft.

9. Bow impact accelerations are greater for the AGC C150-50 in Sea States 2 and 3. In Sea State 4 impact accelerations are roughly the same for both designs -- reaching approximately 7.0g's.

10. Survivability experiments were conducted off-cushion and hove-to, and with and without list. The results show that in Sea State 5 roll and pitch are usually greater for JEFF (B) than JEFF (A). Heave acceleration is about the same for the JEFF boats in this condition.

11. When retracting through surf, the AGC C150-50 experiences greater bow down pitch, which can lead to more solid water on the deck and more frequent slamming. Heave down, conversely, is generally greater for the BAC C150-50.

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2. Aerojet-General Corp., "Amphibious Assault Landing Craft JEFF (A) Model Test Report: Hydrodynamic Tests of the AALC C150-50 Verification Model", Report TR-ACV1000 (July 1971)

3. Aerojet-General Corp., "Detailed Engineering Review Presentation to U.S. Navy: Section 1 - Craft Arrangement and Principal Characteristics; Section 2 - Craft Performance", Technical Report SR-ACV1024 (November 1972)

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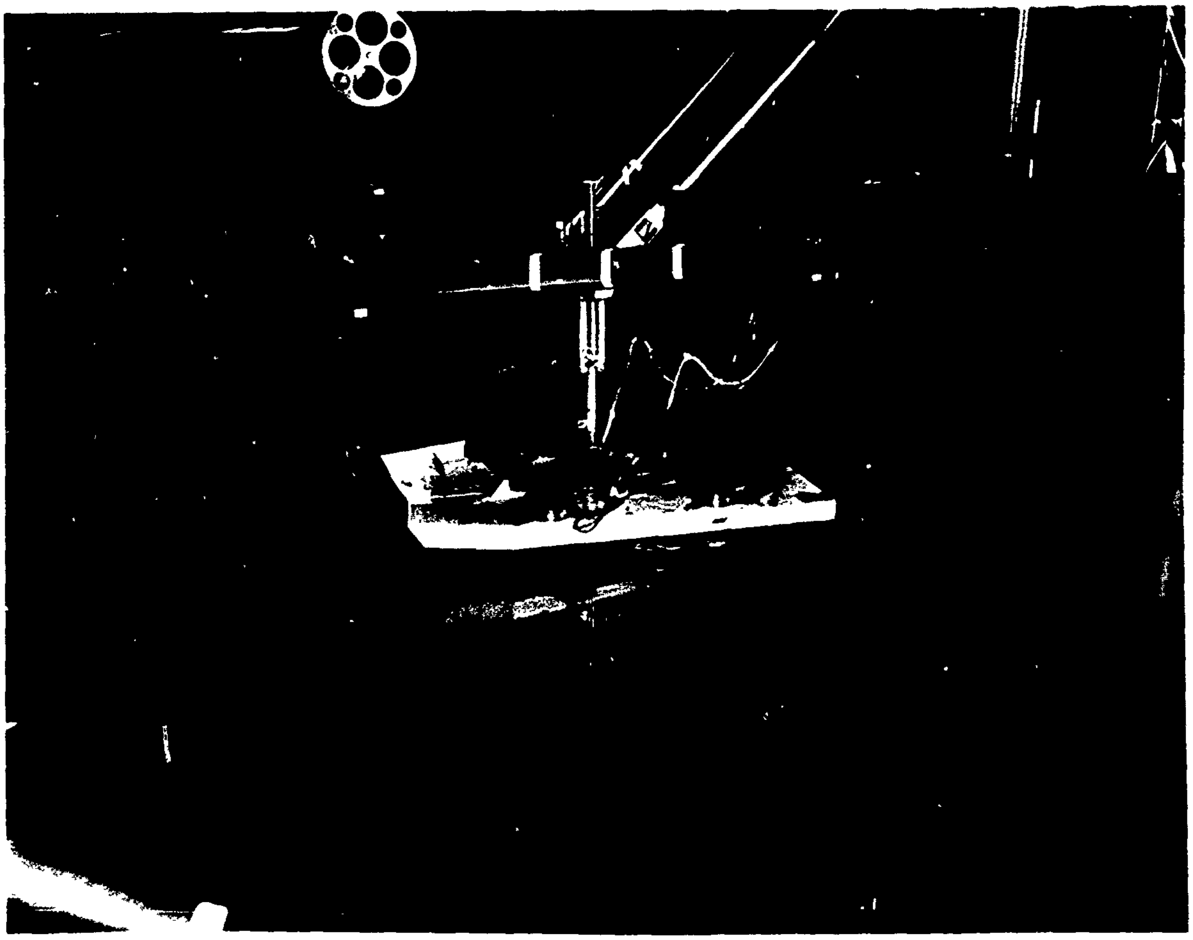
11. Kirkman, K.L., "Model Evaluation of the Performance in Surf of the Aerojet-General Corporation Preliminary Design for the AALC C150-50", Hydronautics, Inc. Technical Report 7009-3 (May 1971)

12. Kirkman, K. L., Model Evaluation of the Performance in Surf of the Bell Aerospace Company Preliminary Design for the AALC C150-50," Hydronautics, Inc. Technical Report 7009-4 (May 1971)



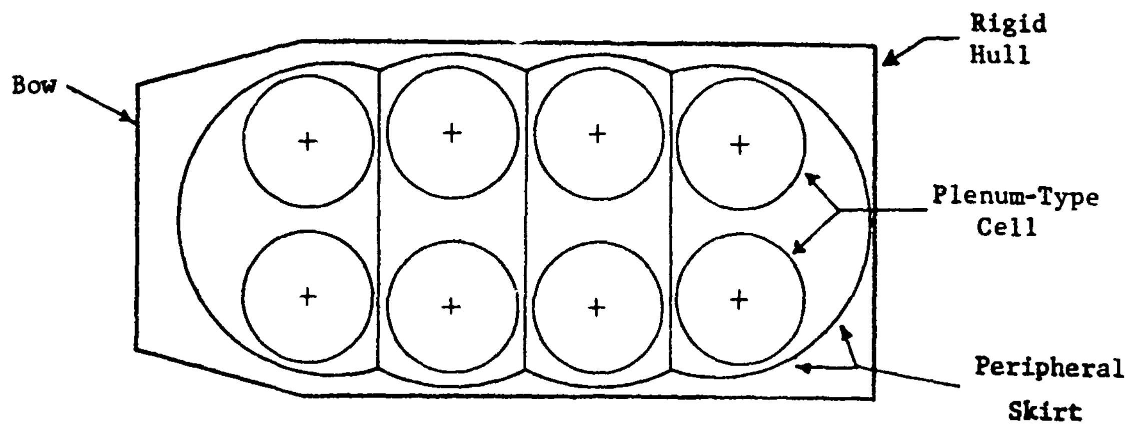


Figure 1 - AGC Model 104 with Multicell Cushion Configuration

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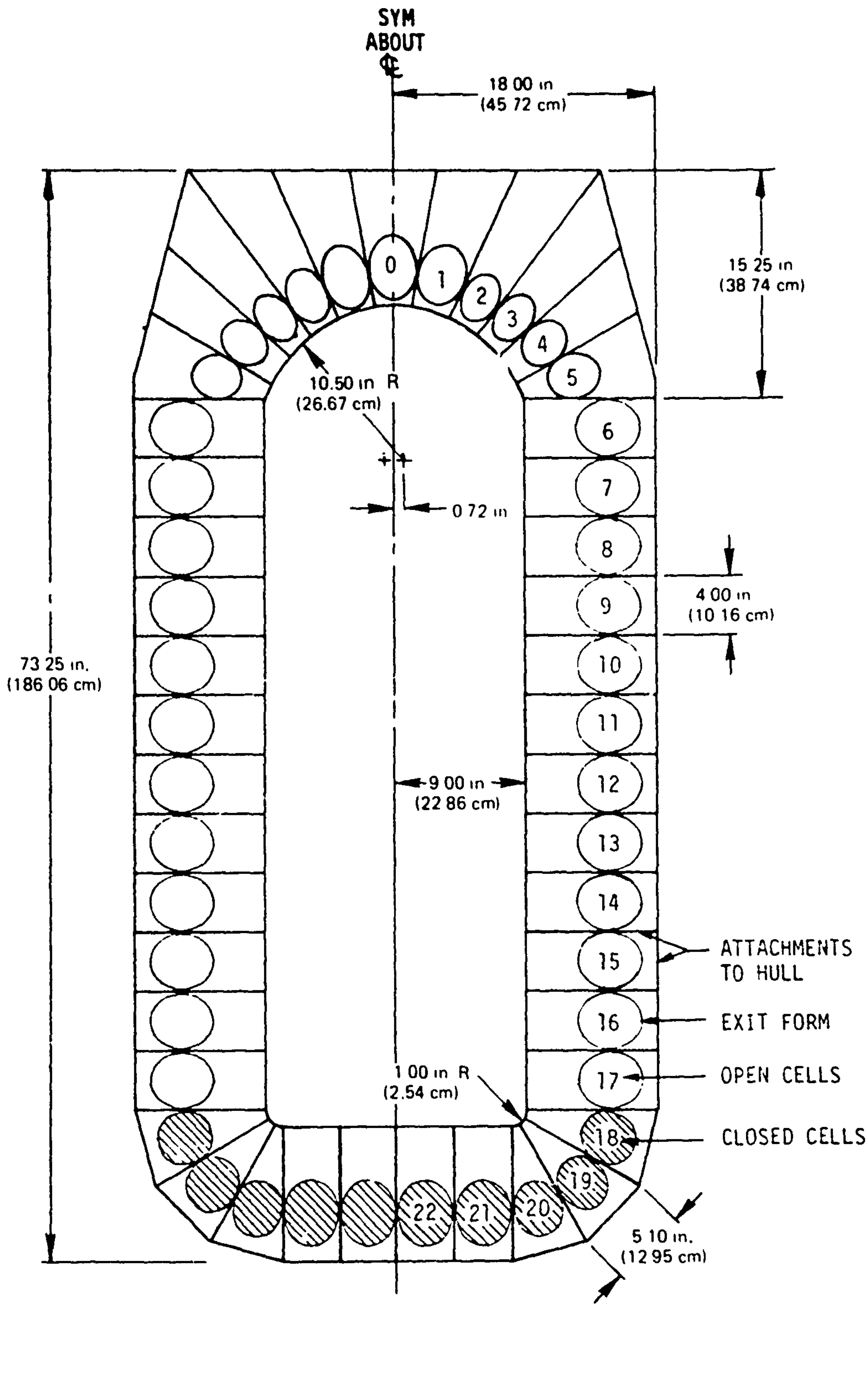

Figure 2 - AGC Model 105 with Peripheral Cell Cushion Configuration

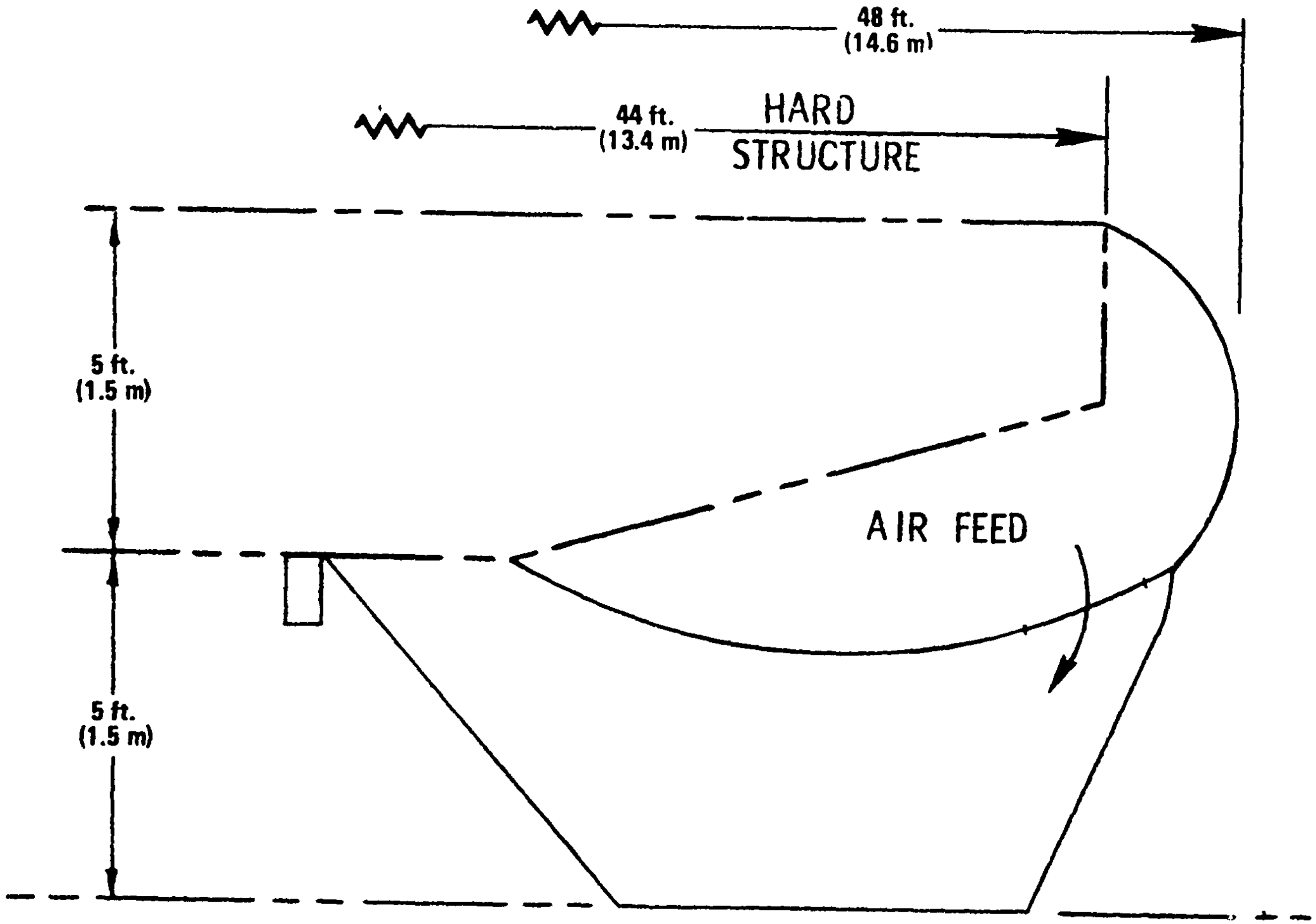

Figure 3 - Side Section of Loop Peripheral Cell Skirt System

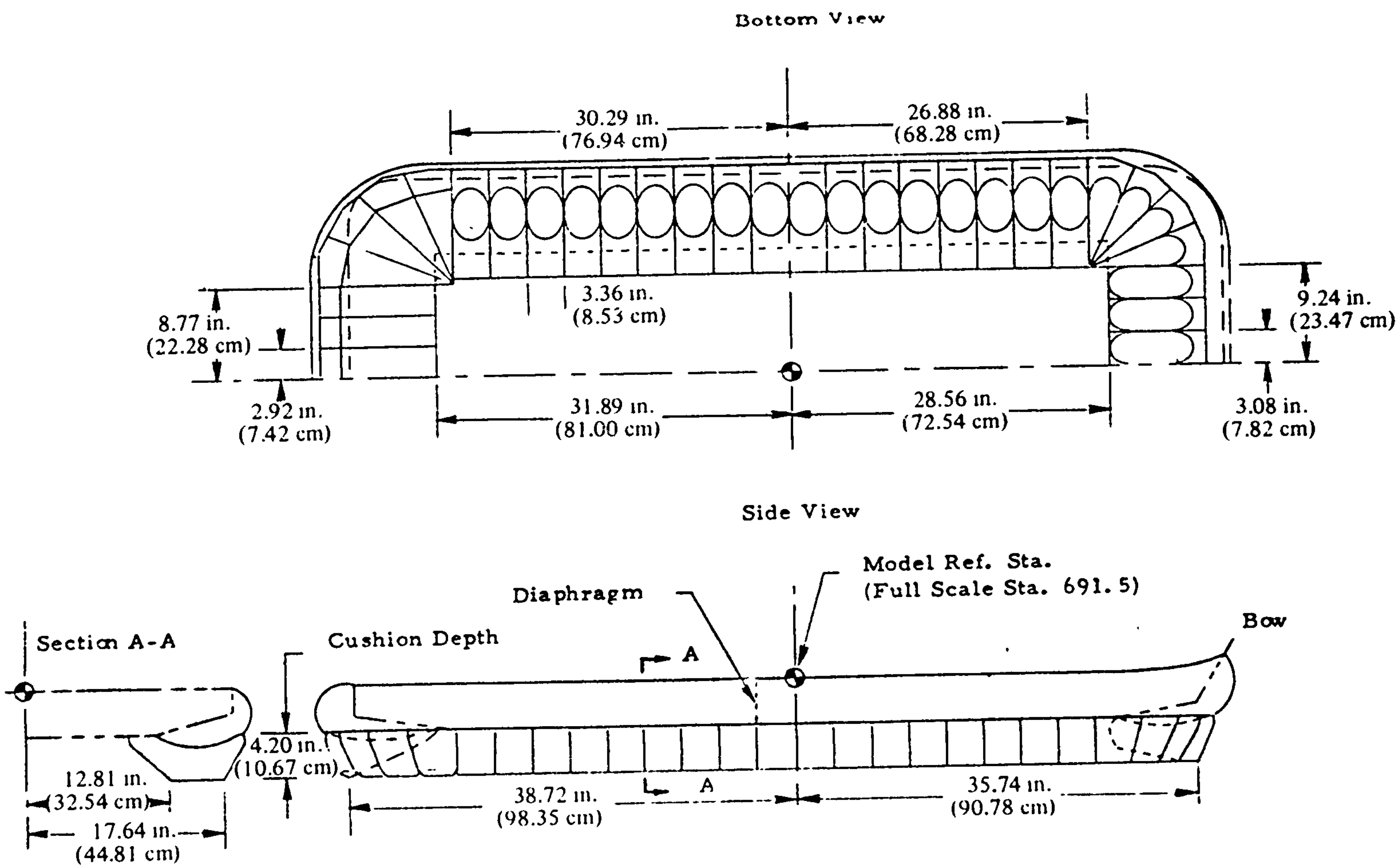

Figure 4 - AGC JEFF(A) 7/100-Scale Verification Model with Basic Skirt

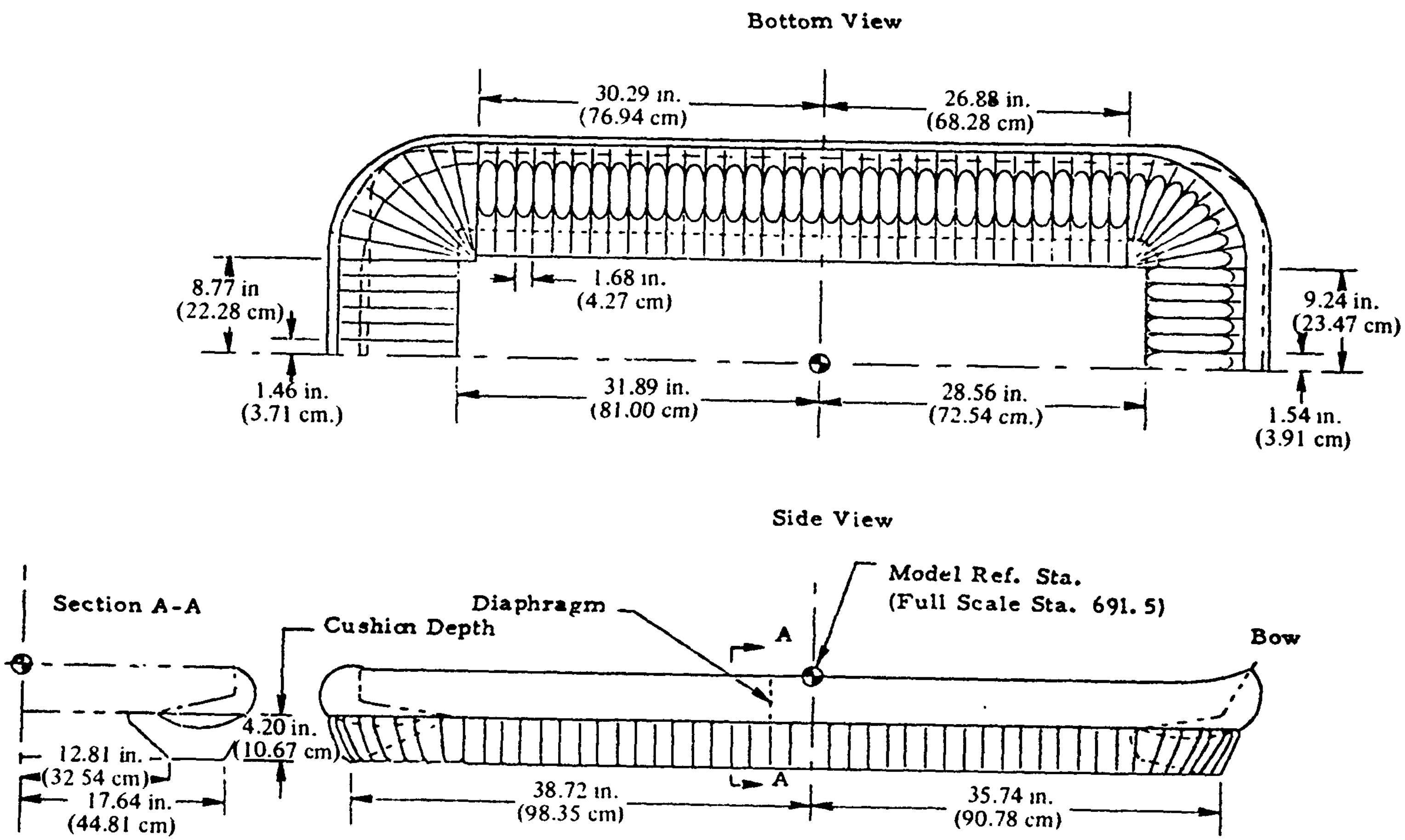

Figure 5 - AGC JEFF(A) 7/100-Scale Verification Model with Half Width Cells

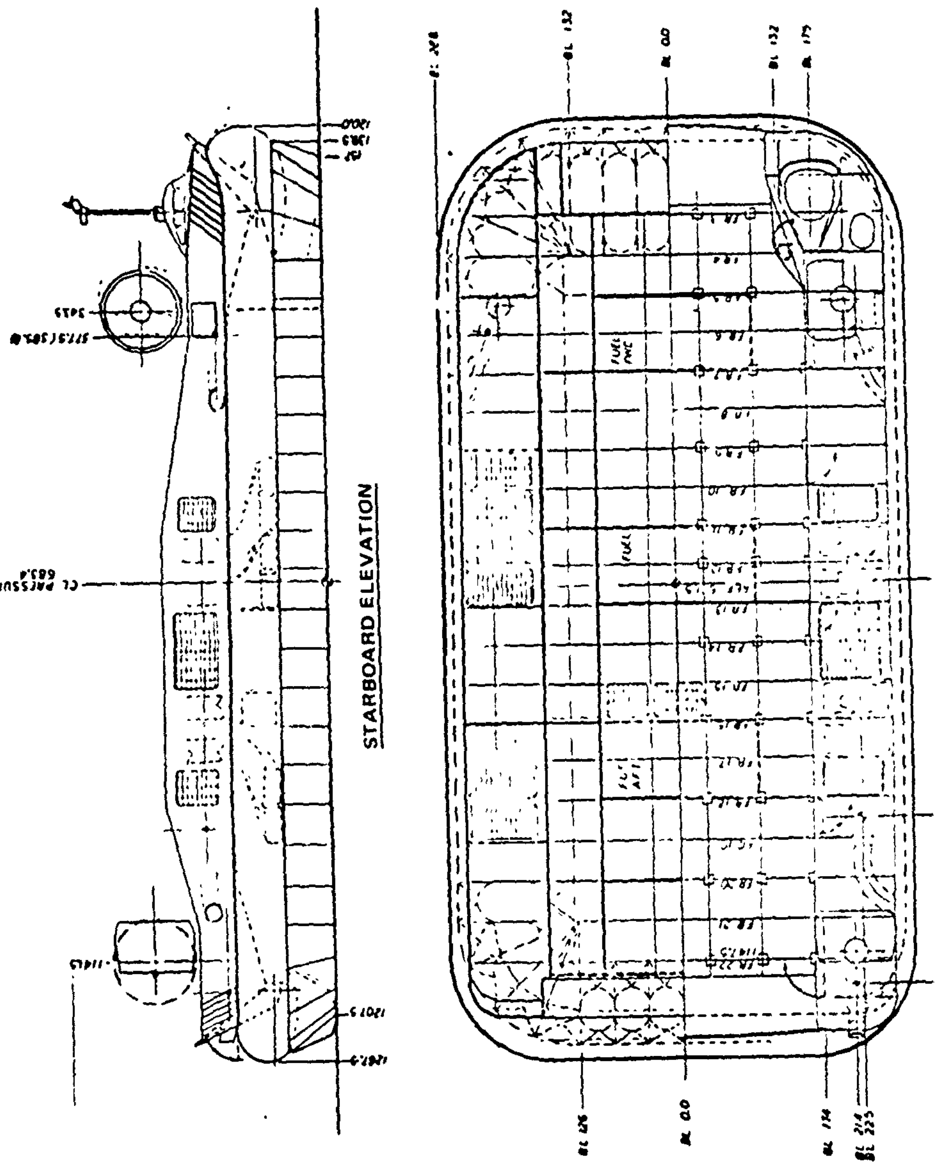

Figure 6 - AGC JEFF(A)-3 Concept

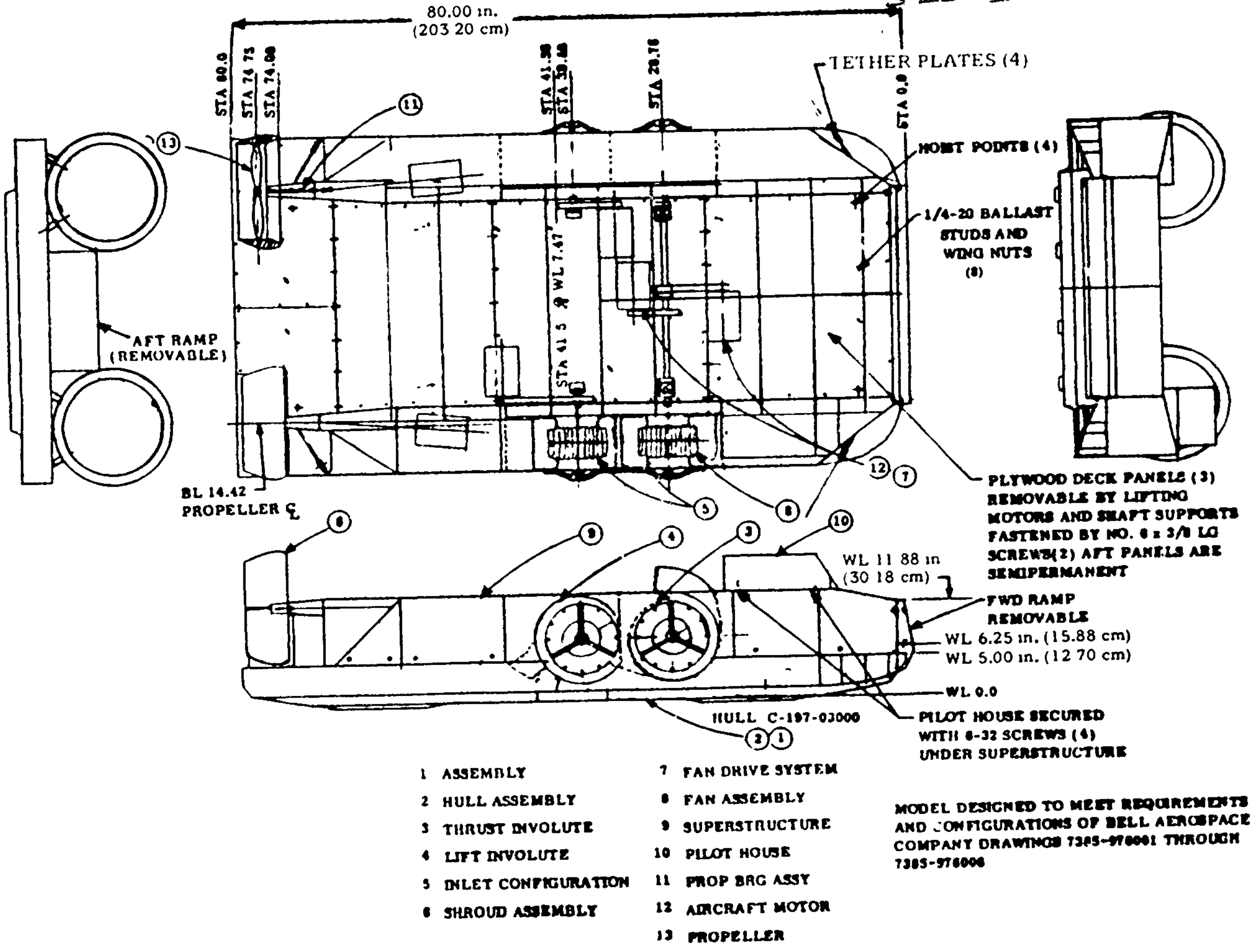

Figure 7 - BAC B-17 Model of C150-50 Design

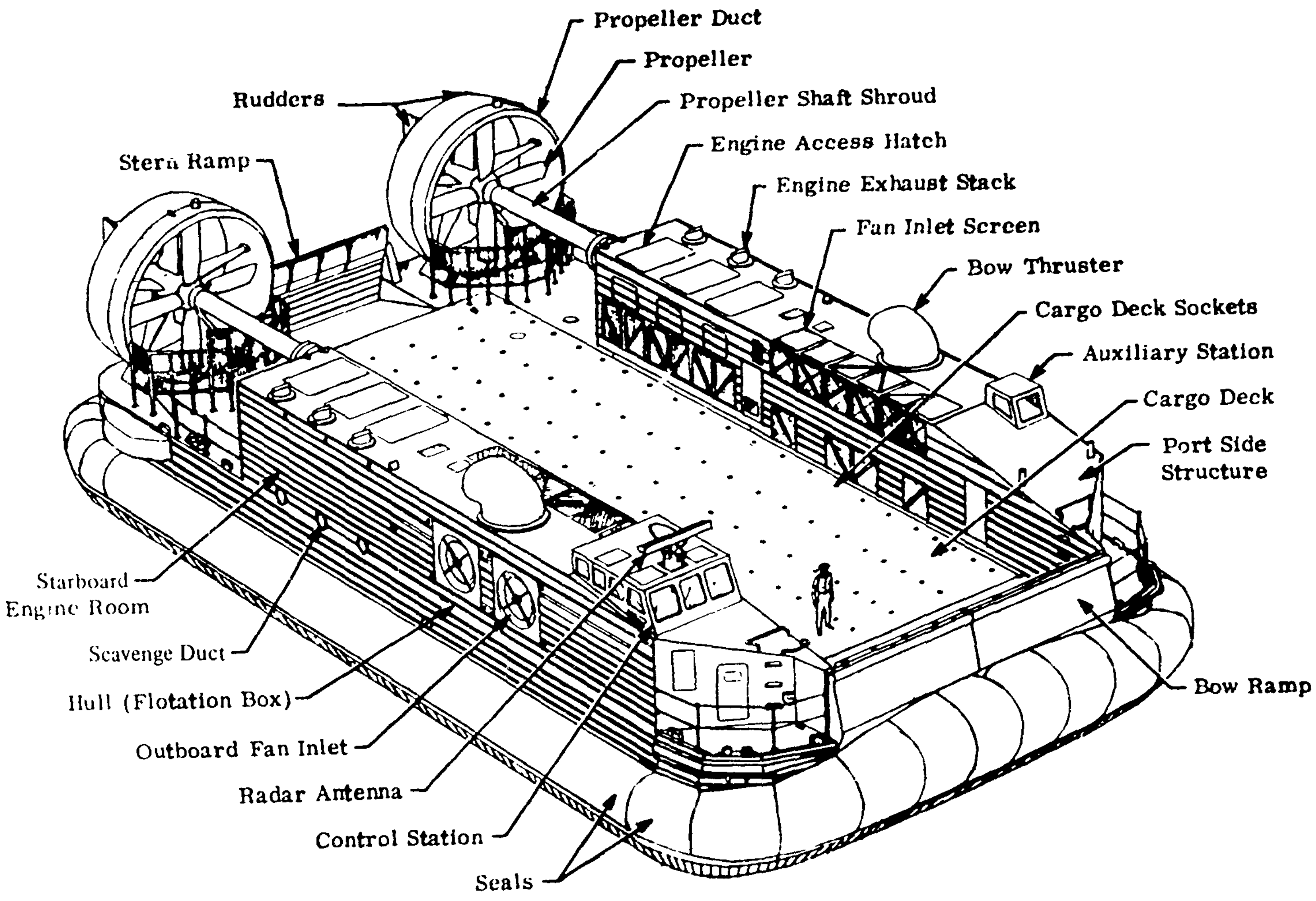

Figure 8 - BAC C150-50 Prototype

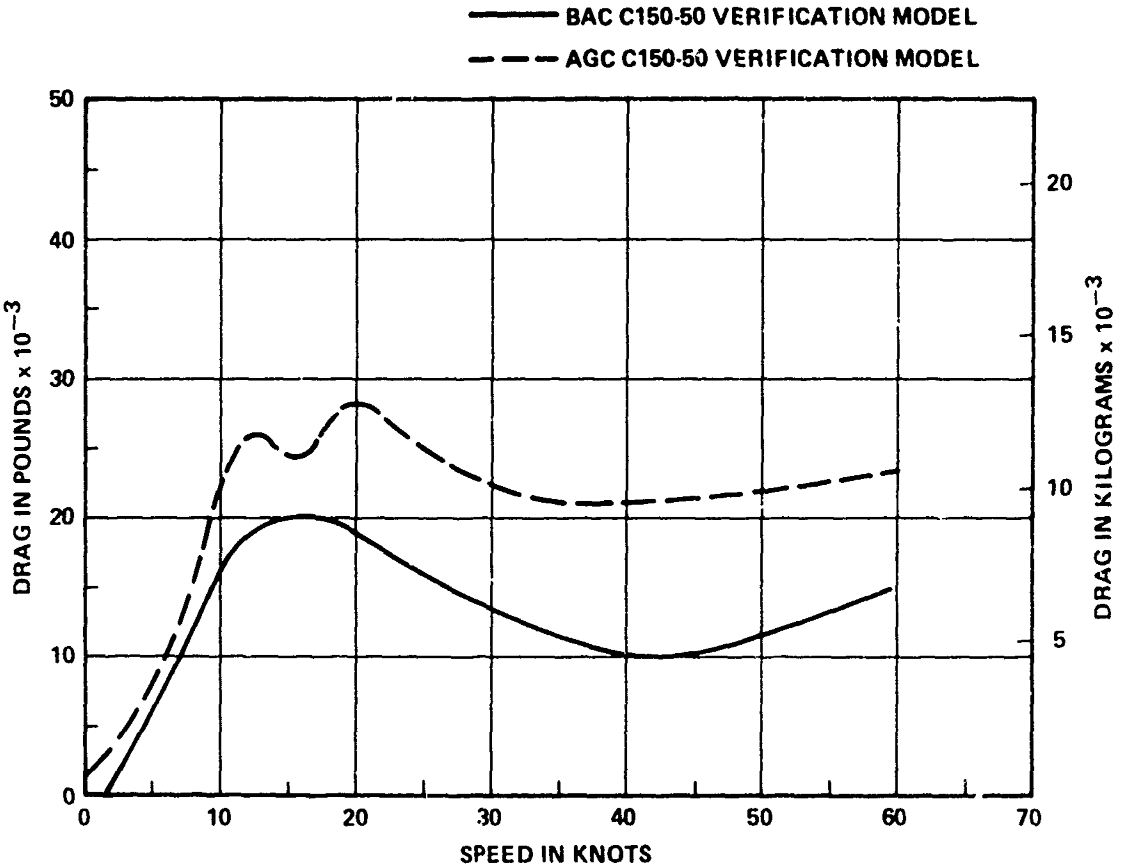

Figure 9 - Comparison of Calm Water Drag for the BAC and AGC C150-50 Designs; Results from Model Experiments at DTNSRDC

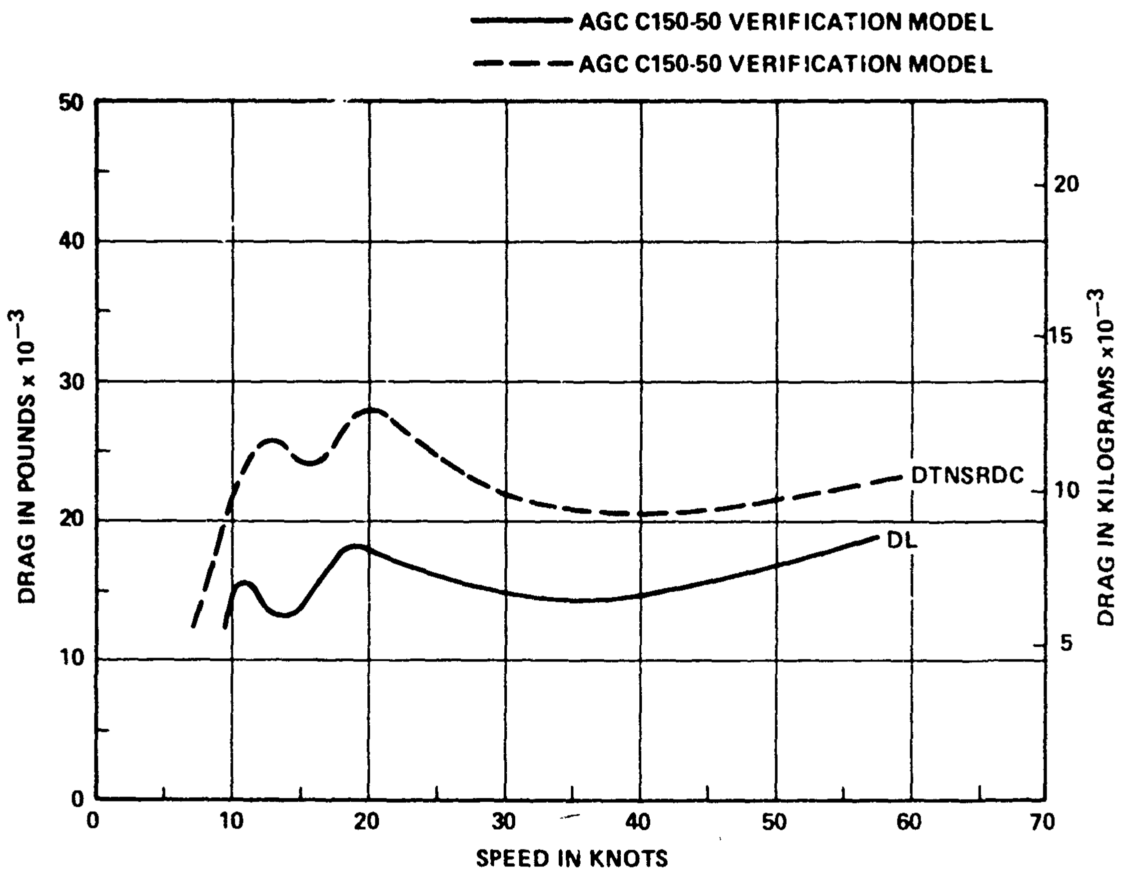

Figure 10 - Comparison of Calm Water Drag for AGC C150-50 Design from Model Experiments at DTNSRDC and DL

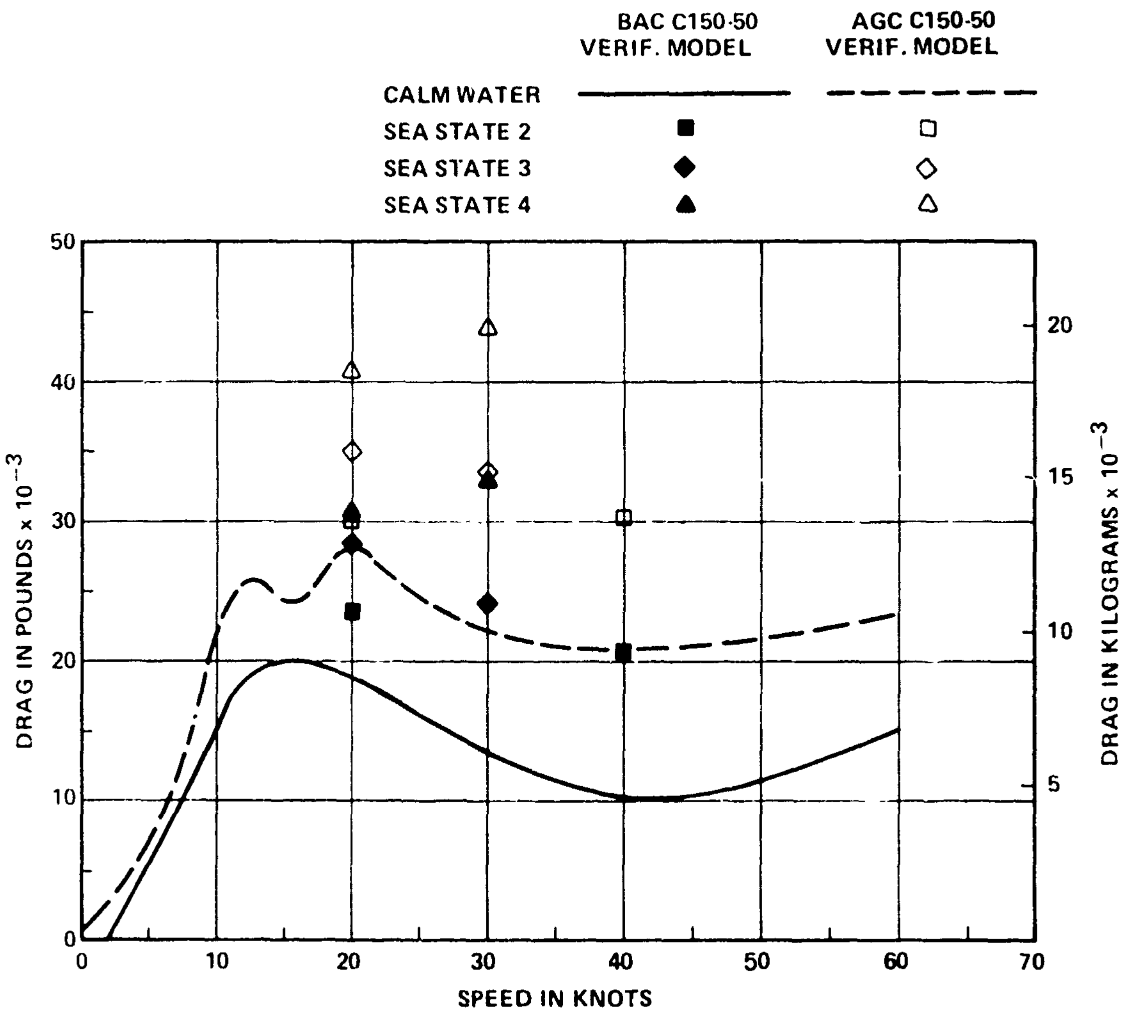

Figure 11 - Comparison of Drag in a Seaway for the BAC and AGC C150-50 Designs; Results from Model Experiments at DTNSRDC

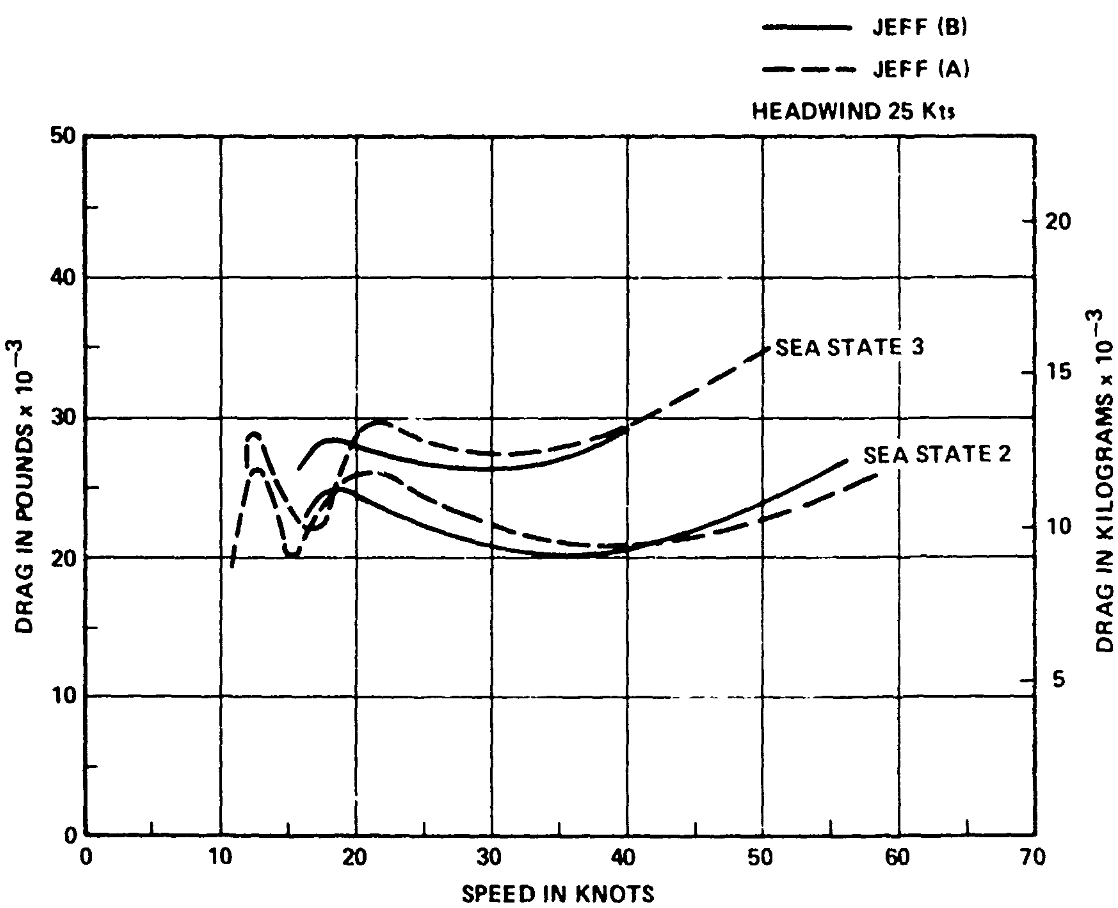

Figure 12 - Drag in Waves from the BAC and AGC Detailed Engineering Reviews

AGC C150-50 VERIFICATION MODEL
MODEL SCALE FAN RPM = 8,600

SEA STATE		FULL SCALE WEIGHT		MODEL SCALE TRIM MOMENT	
		lb	kg	in.-lb.	cm-kg
2	———	344,064	156,065	56.7 aft	65.3 aft
2	– – – –	344,064	156,065	62.0 fwd	71.4 fwd
2	□	337,000	152,861		
4	—— ——	335,872	152,349	83.0 aft	95.6 aft
4	△	337,000	152,861		

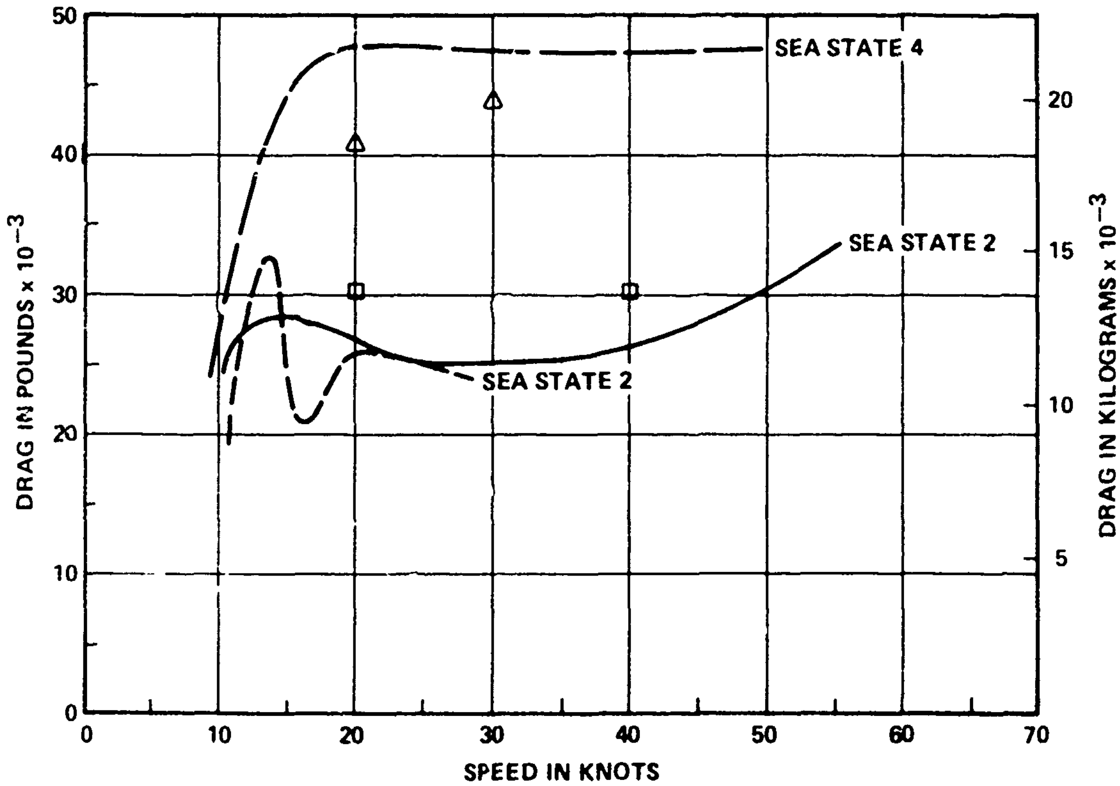

Figure 13 - Drag in Waves for the AGC C150-50 Verification Model as Presented in the AGC PDSR and Obtained at DTNSRDC

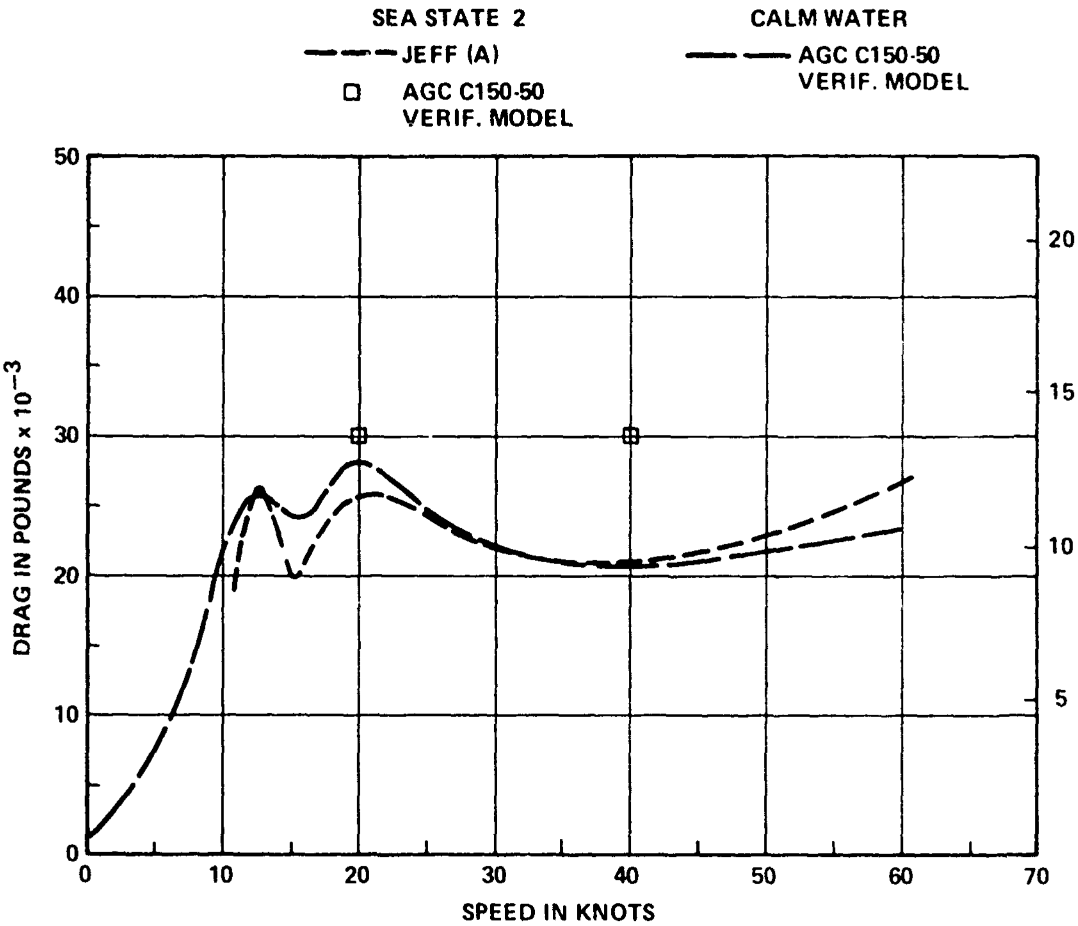

Figure 14 - Drag in Waves for the JEFF (A) and AGC C150-50 Verification Models as Presented in the AGC DER and Obtained at DTNSRDC

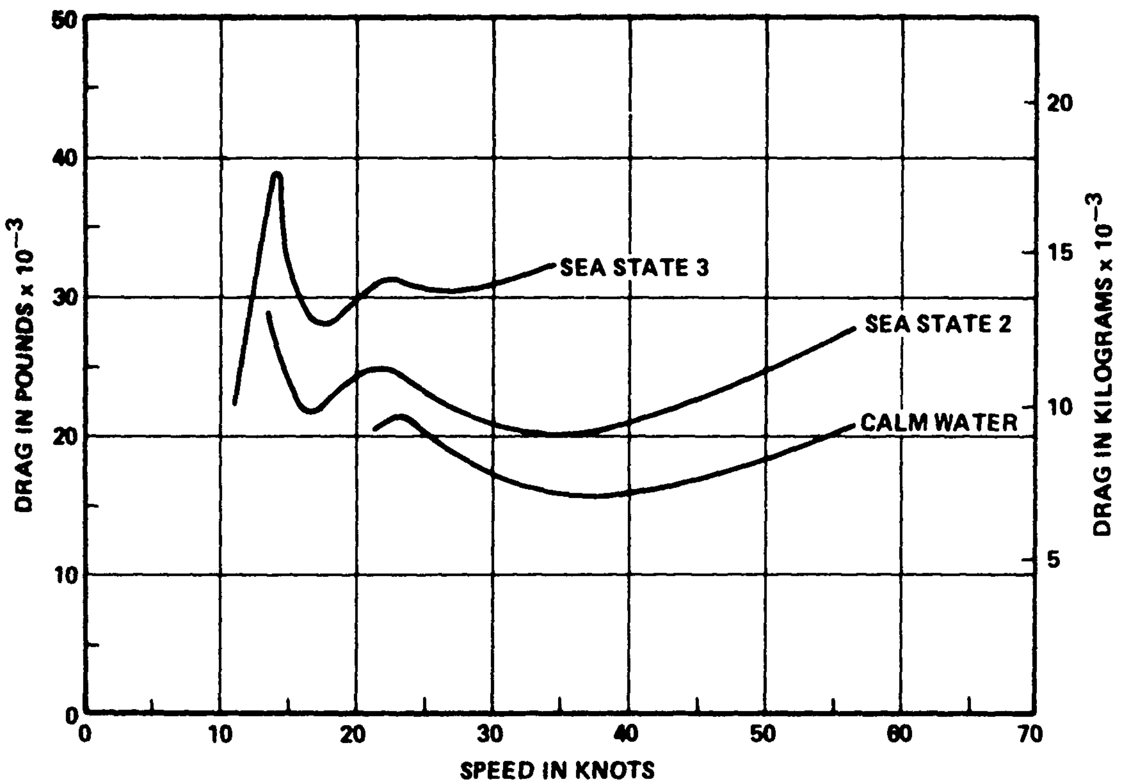

Figure 15 - Variation of Drag with Sea State

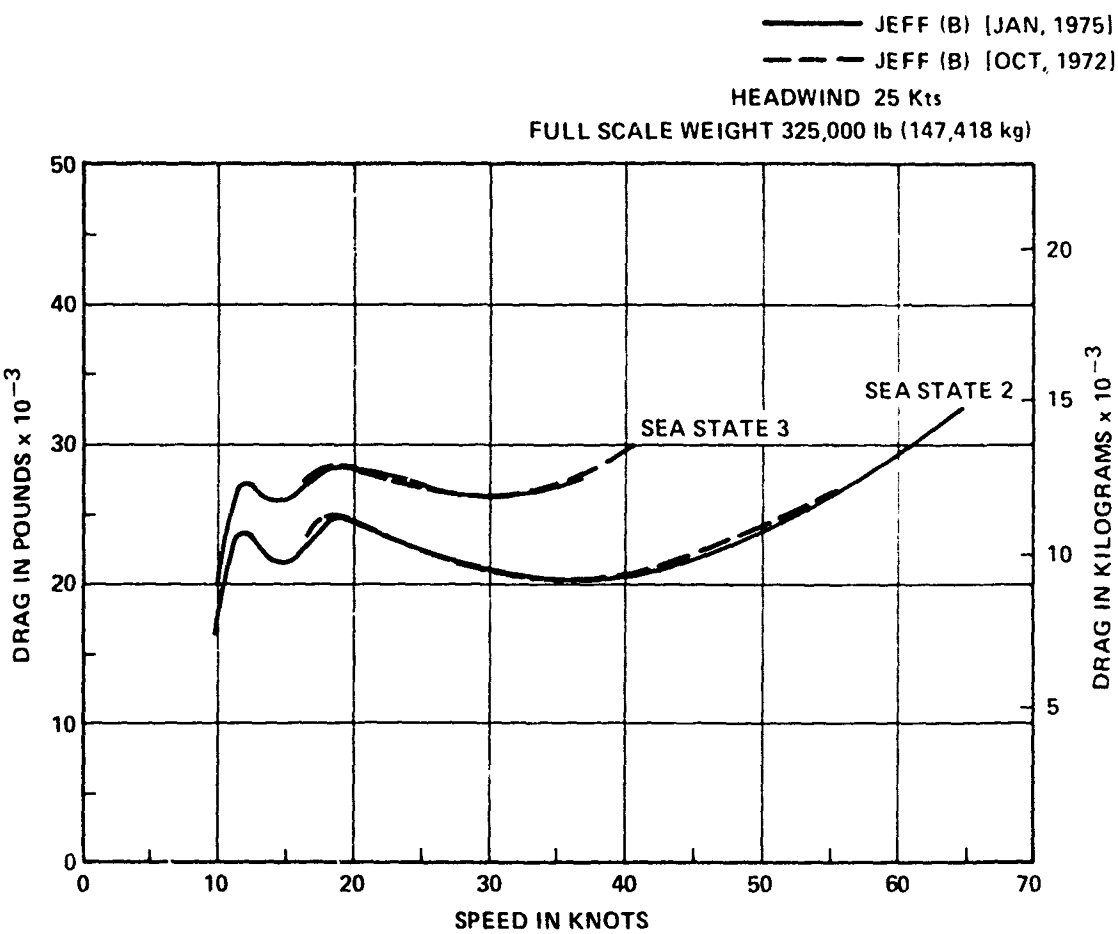

Figure 16 - Drag in Waves for the JEFF(B)

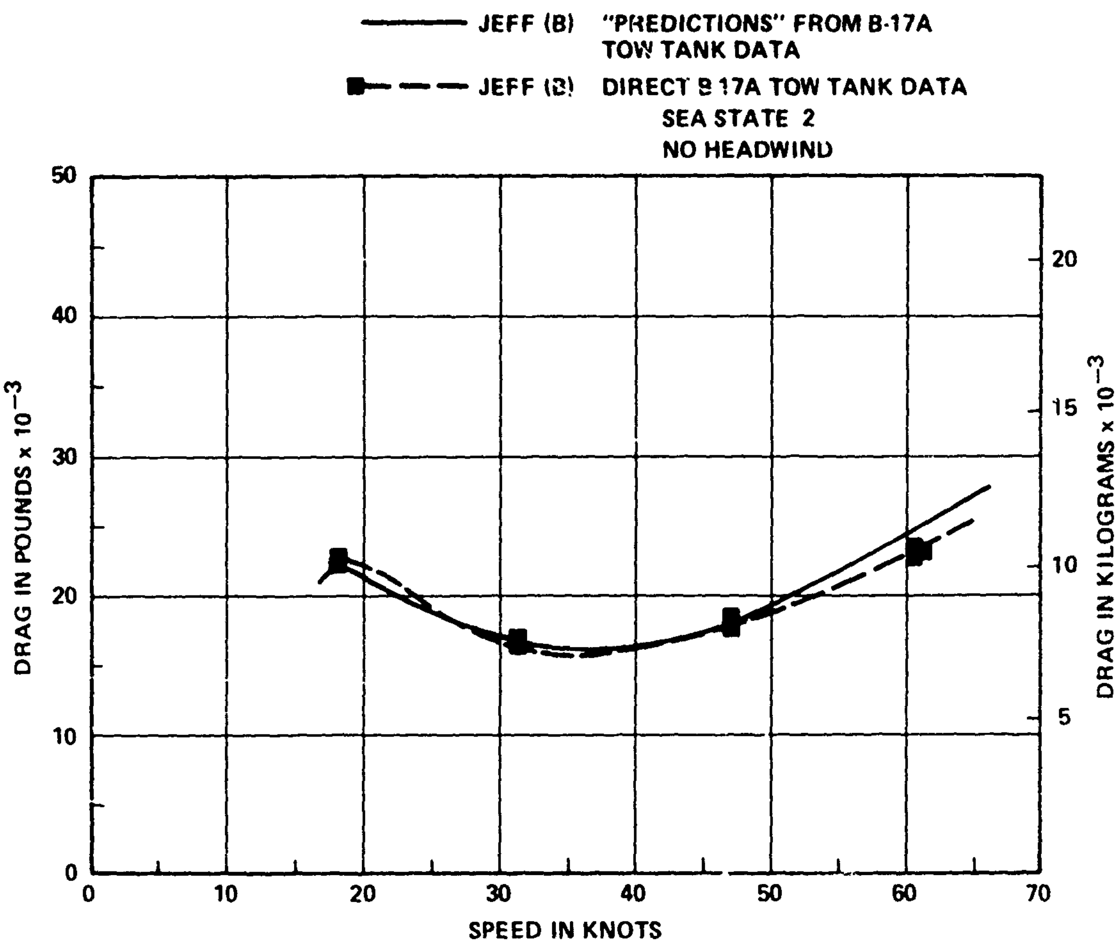

Figure 17 - Comparison of Drag for JEFF(B) in Sea State 2 from Direct Froude Scaling and Froude Scaling with Corrections

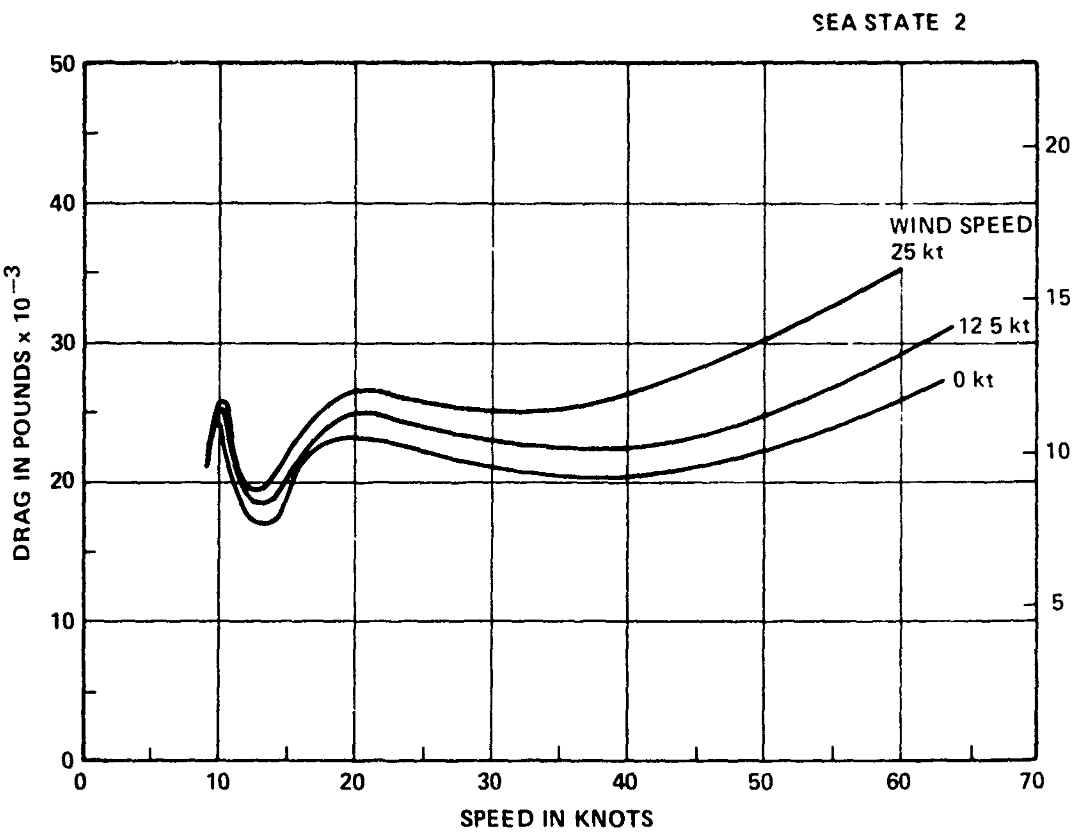

Figure 18 - Effect of Wind Speed on Drag

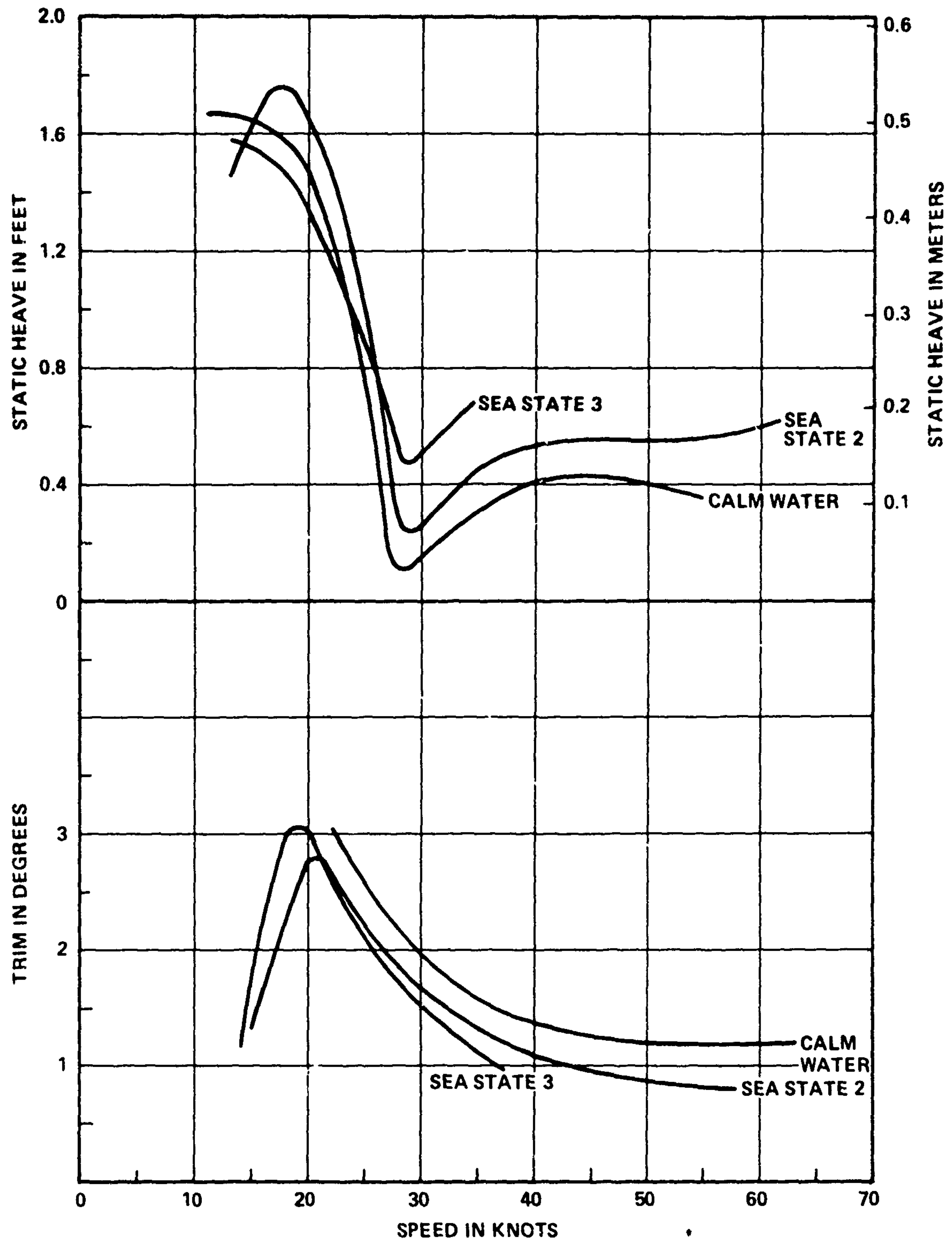

Figure 19 - Effect of Sea State on Trim and Static Heave

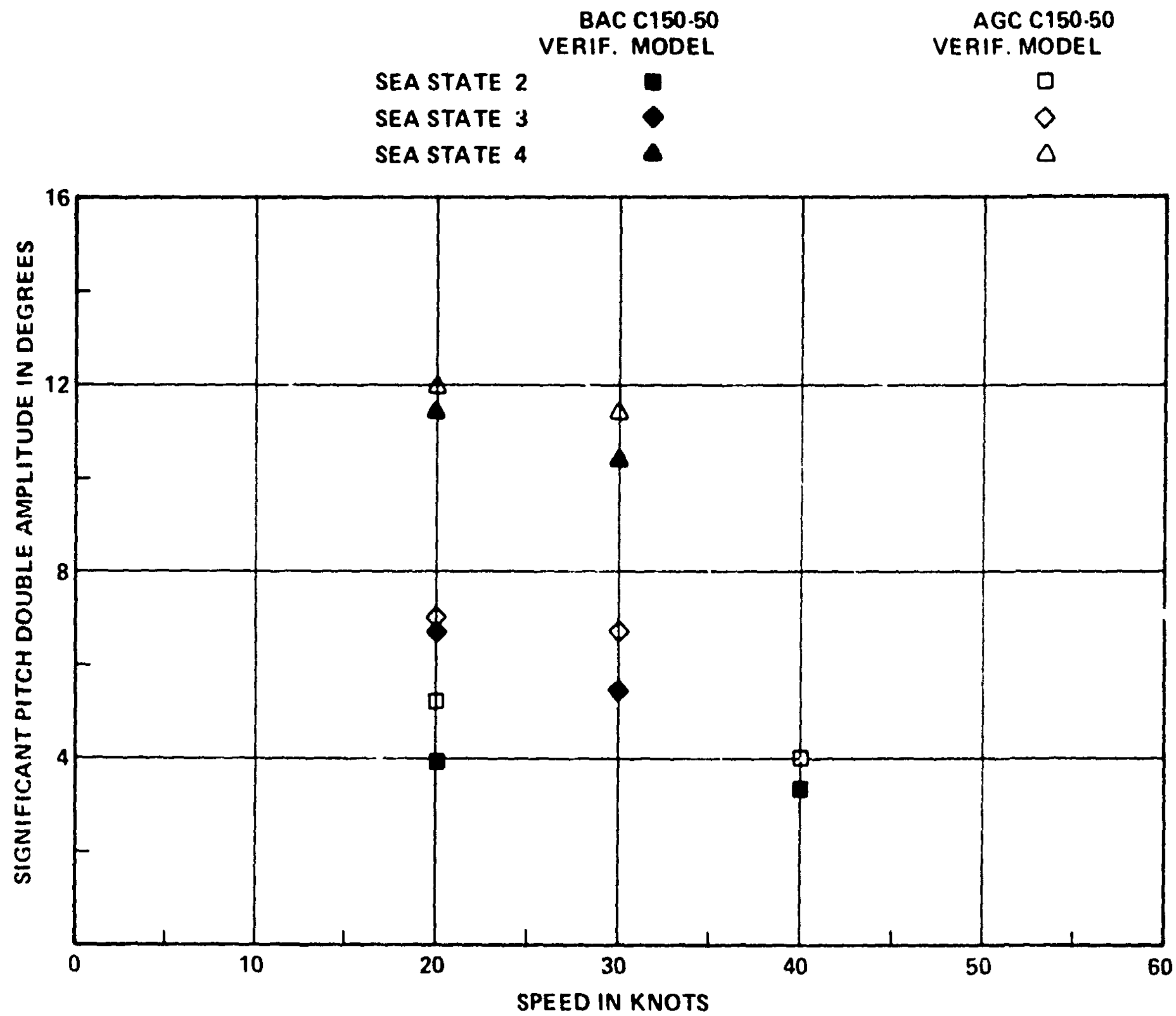

Figure 20 - Comparison of Pitch for the BAC and AGC C150-50 Verification Models

Figure 21 - Wave Spectra for C150-50
Verification Model Experiments
(full scale)

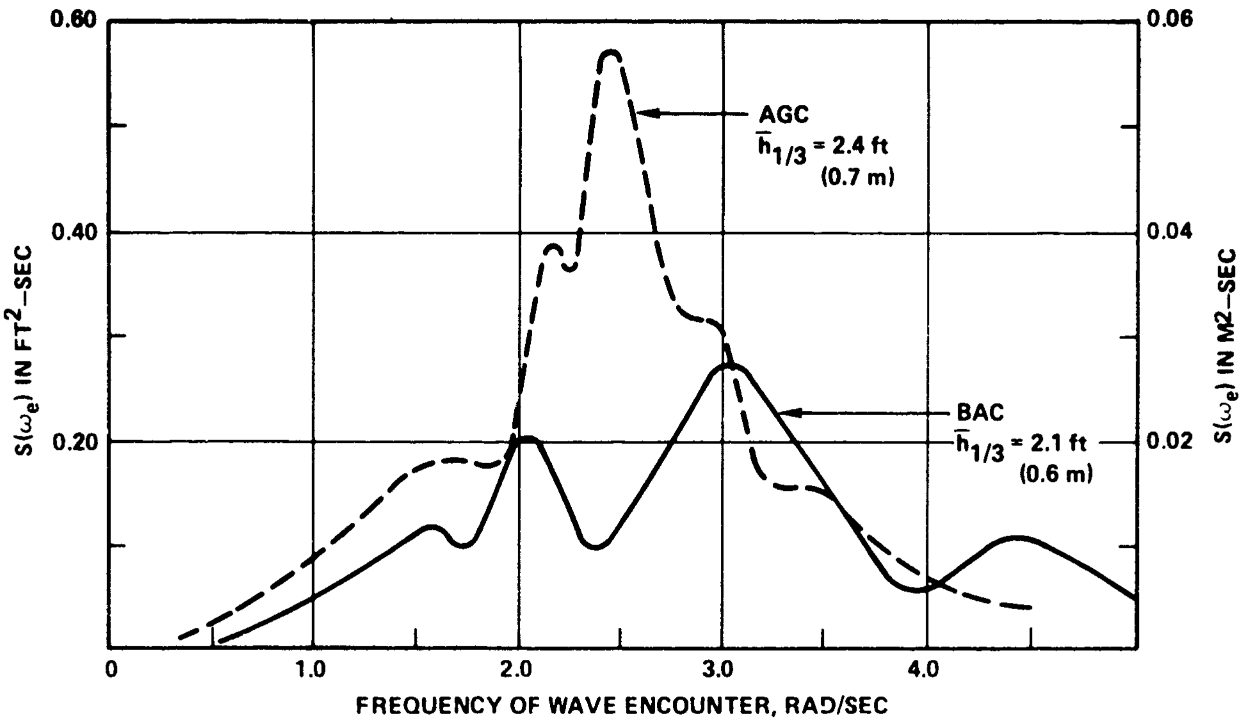

Figure 21a - Sea State 2, Craft Speed 20 Knots

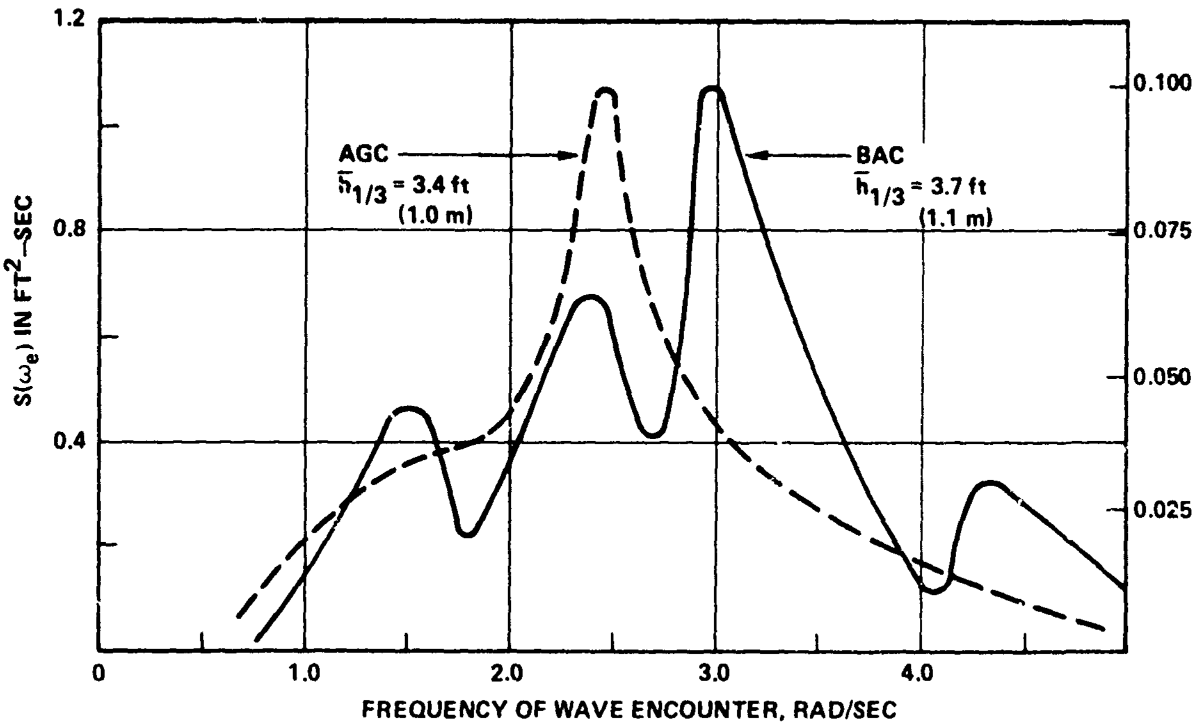

Figure 21b - Sea State 3, Craft Speed 20 Knots

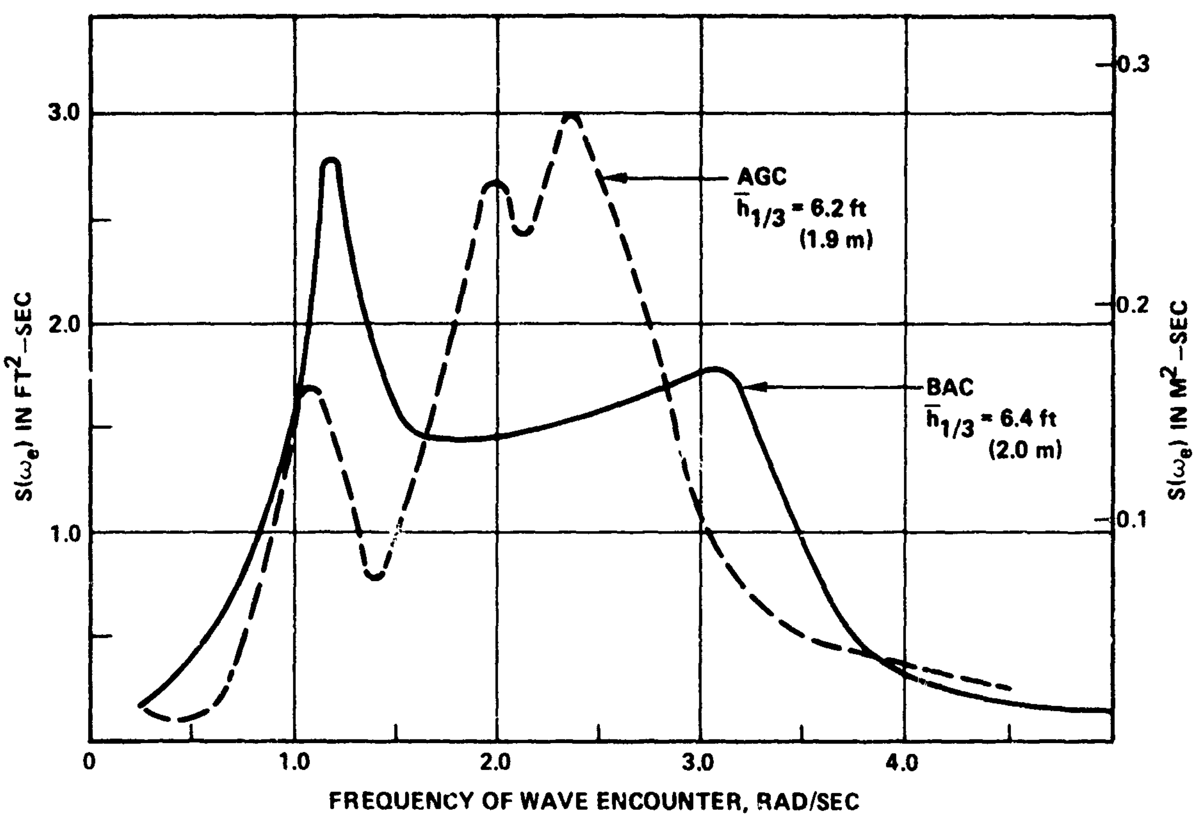

Figure 21c - Sea State 4, Craft Speed 20 Knots

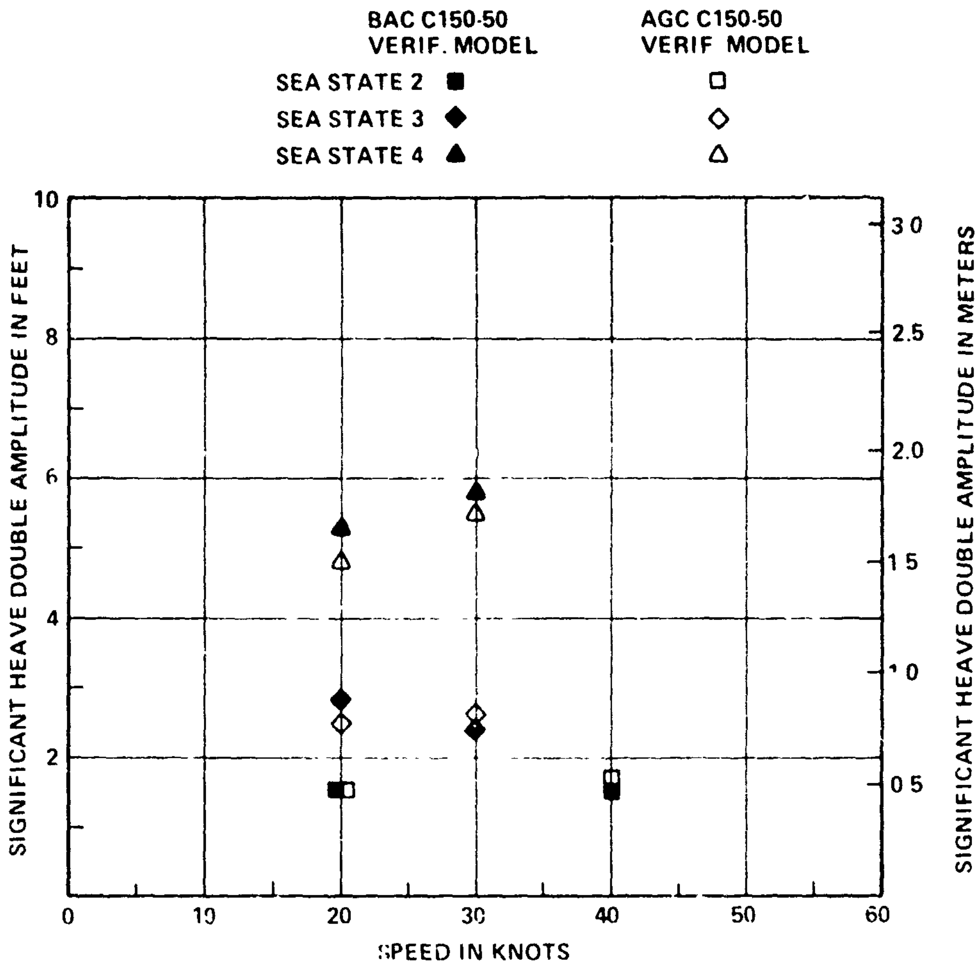

Figure 22 - Comparison of Heave for the BAC and AGC C150-50 Verification Models

Figure 23 - Histograms of Pitch and Heave for the BAC and AGC C150-50 Verification Models

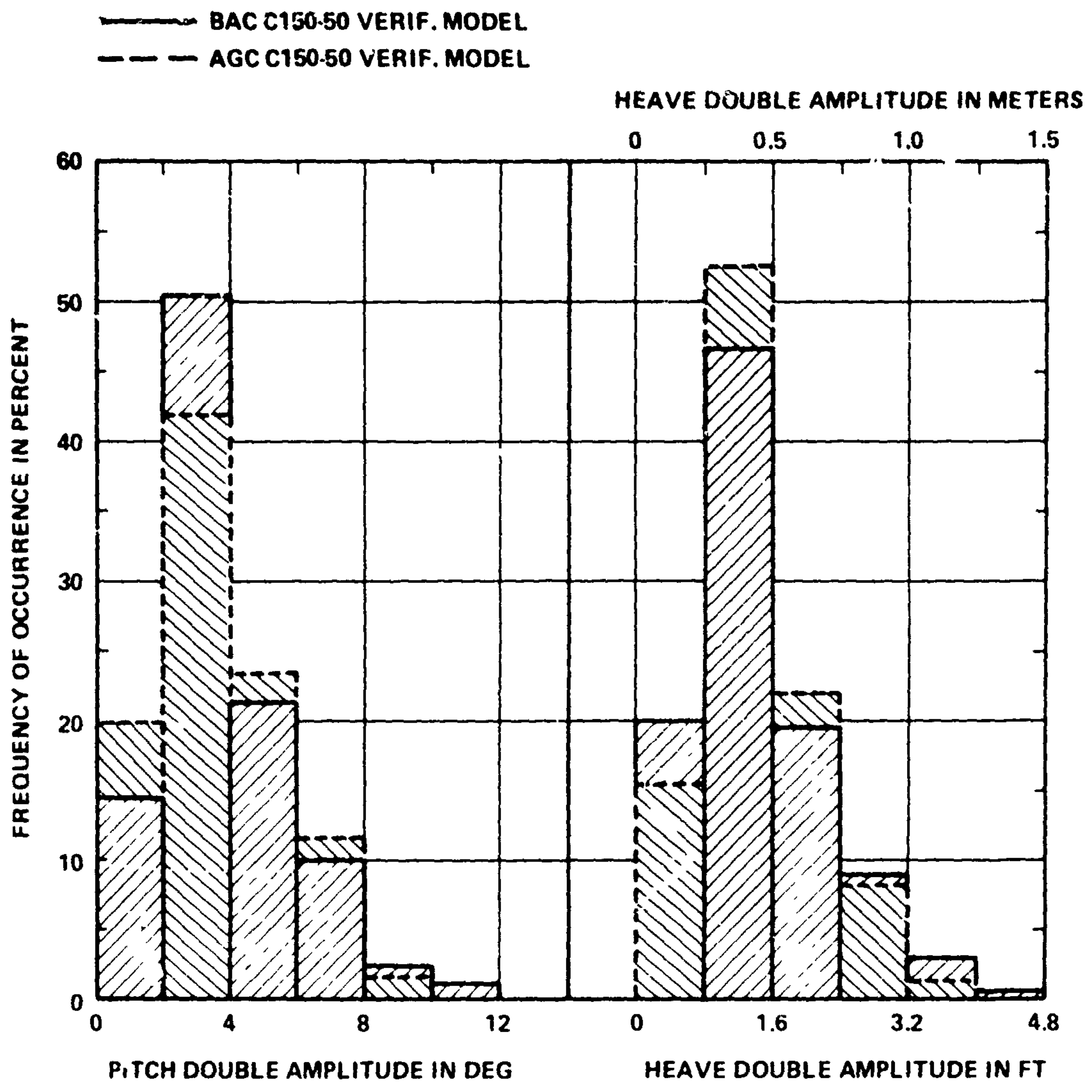

Figure 23a - Sea State 3, Craft Speed 20 Knots

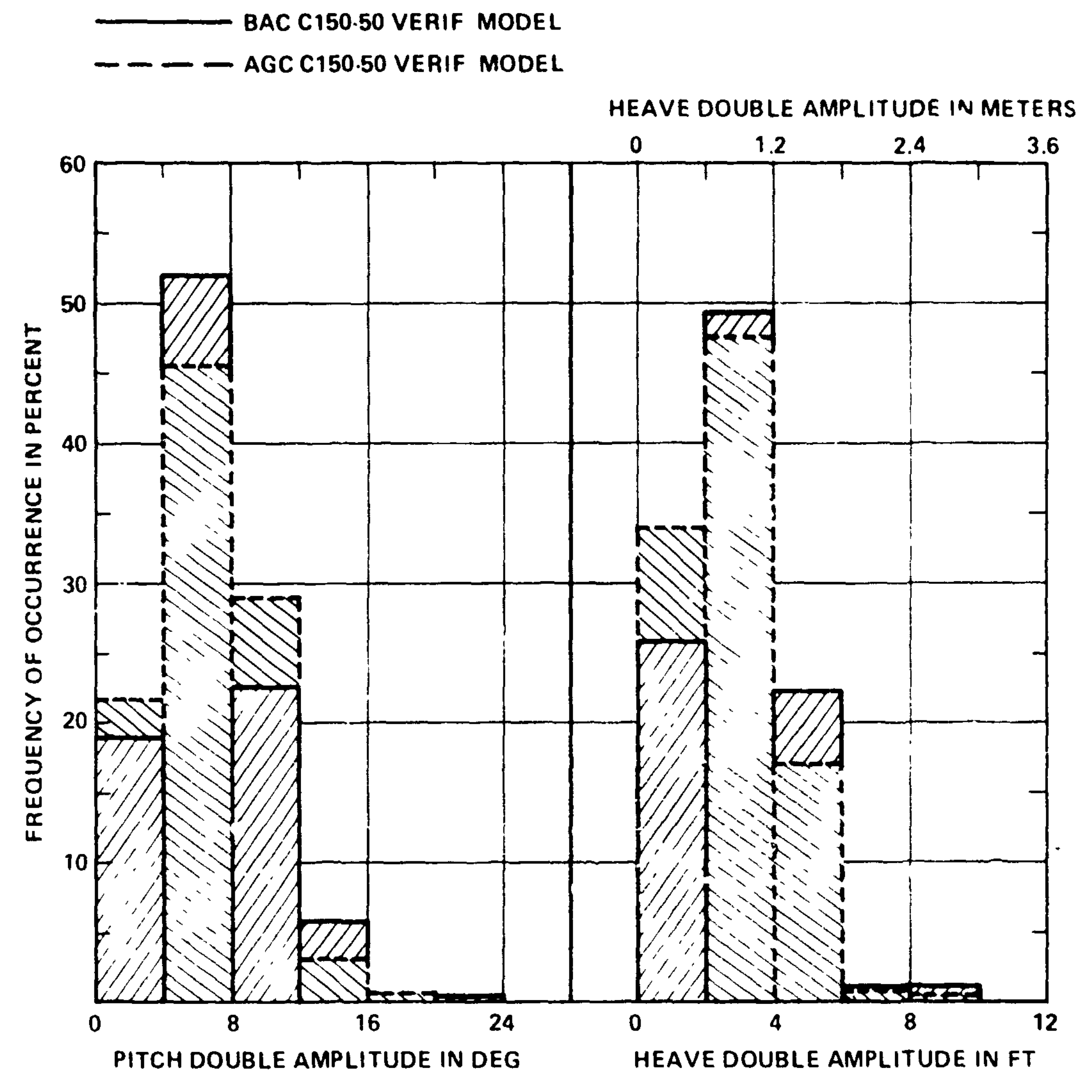

Figure 23b - Sea State 4, Craft Speed 20 Knots

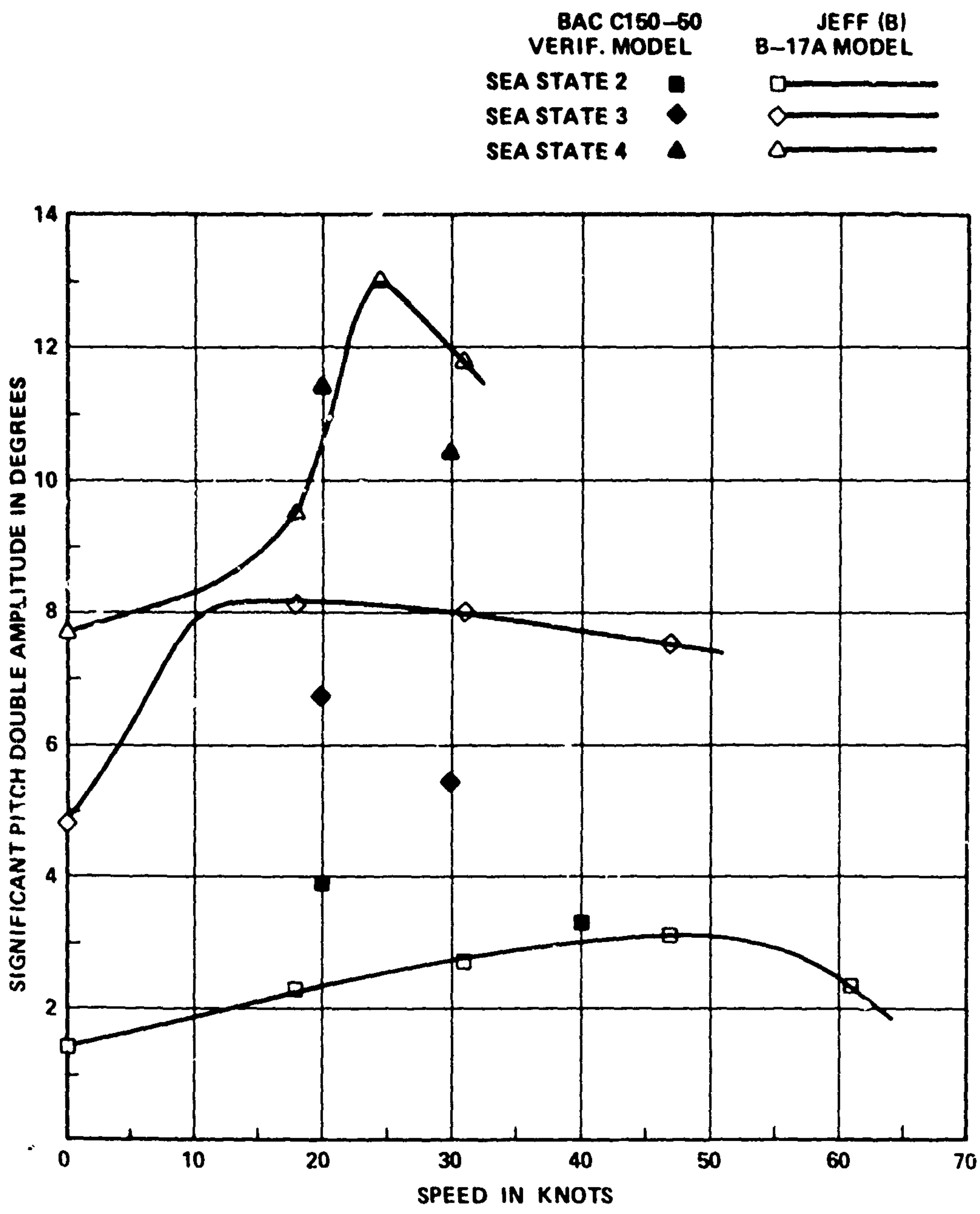

Figure 24 - Comparison of Pitch for the BAC C150-50 and JEFF(B)

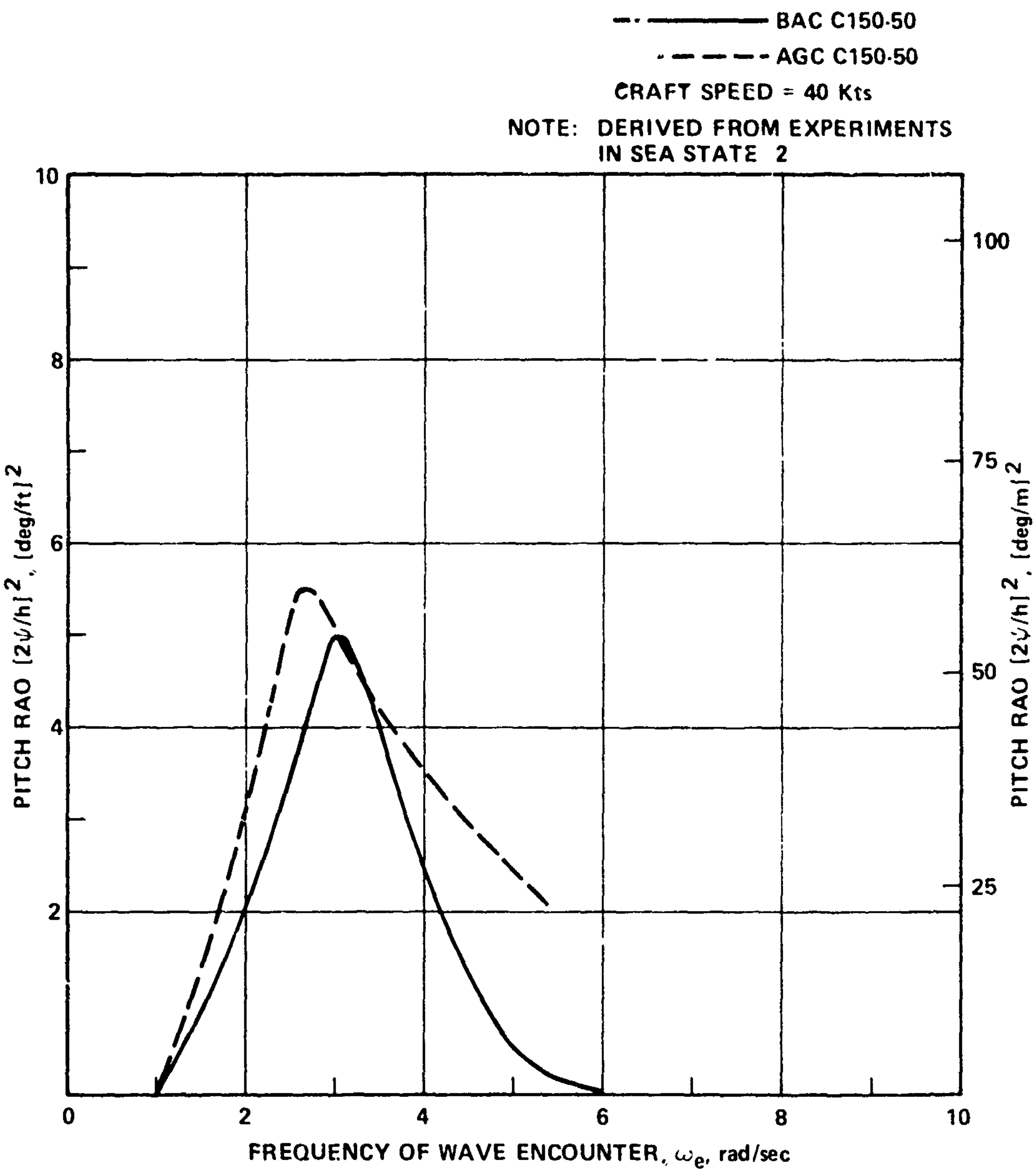

Figure 25 - Pitch Response Amplitude Operators for the BAC and AGC C150-50 Verification Models at a Speed of 40 Knots

Figure 26 - Pitch Response Amplitude Operators for the BAC and AGC C150-50 Verification Models at a Speed of 30 Knots

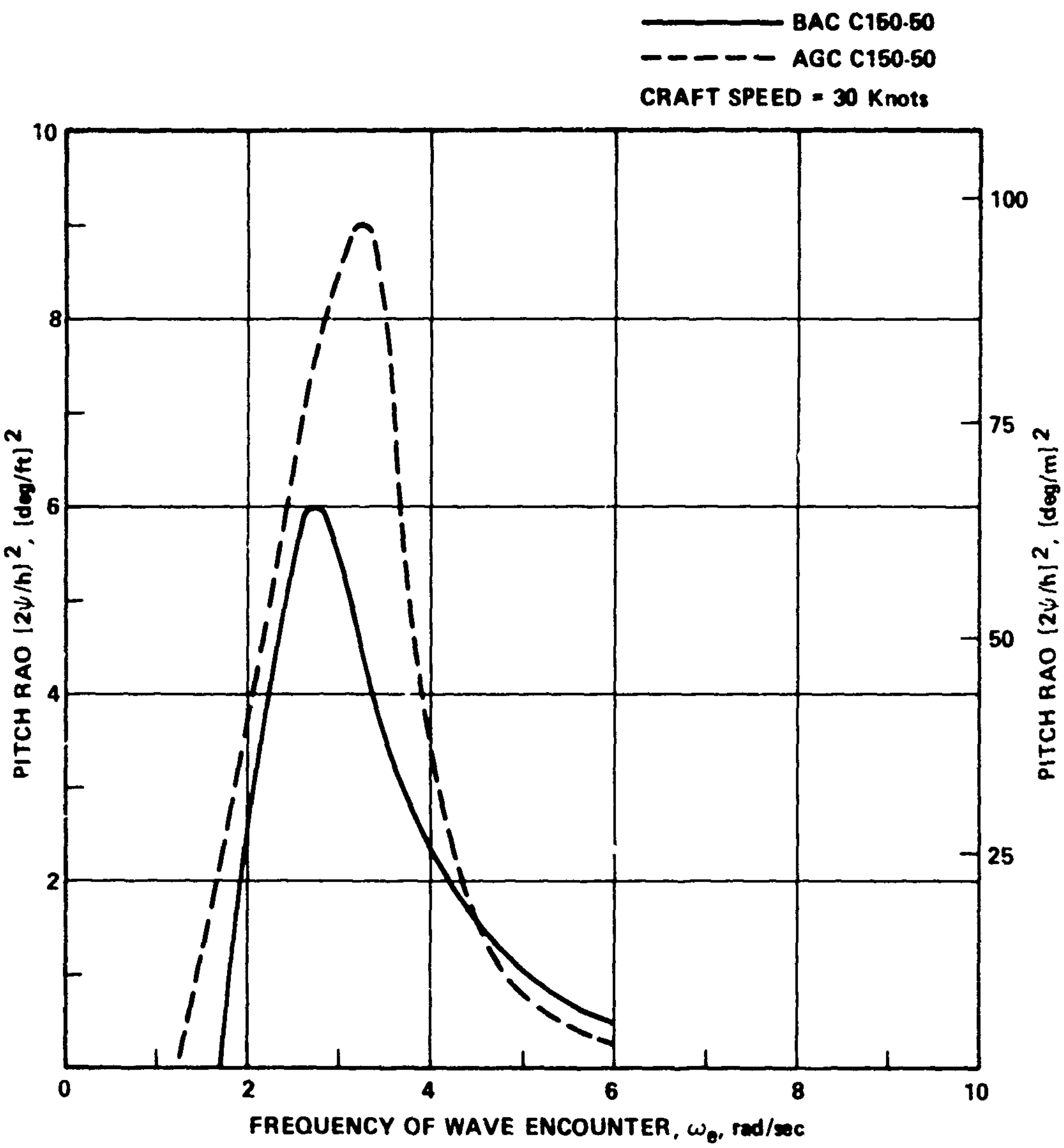

Figure 26a - Results from Experiments in Sea State 3

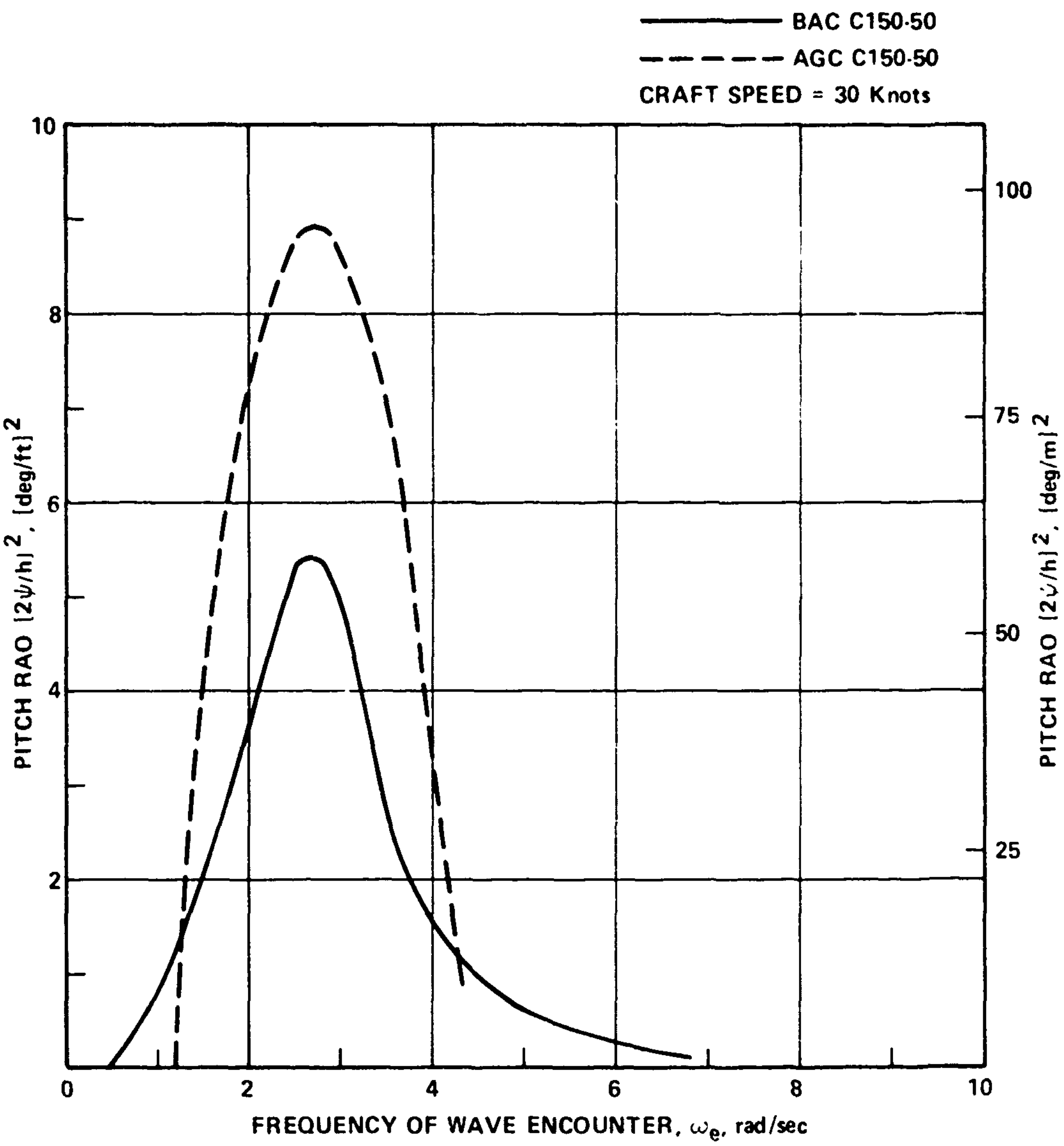

Figure 26b - Results from Experiments in Sea State 4

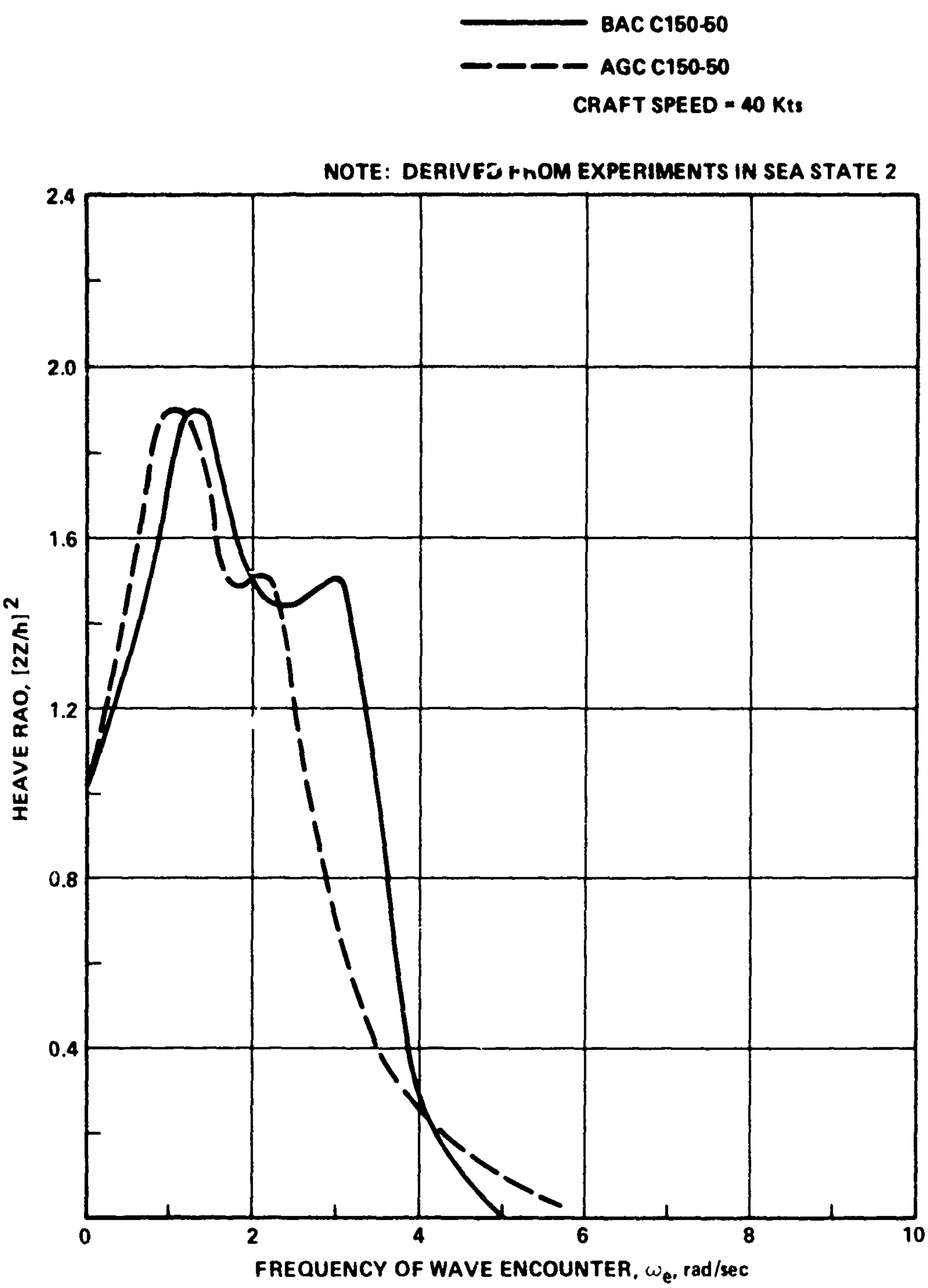

Figure 27 - Heave Response Amplitude Operators for the BAC and AGC C150-50 Verification Models at a Speed of 40 Knots

Figure 28 - Heave Response Amplitude Operators for the BAC and AGC C150-50 Verification Models at a Speed of 30 Knots

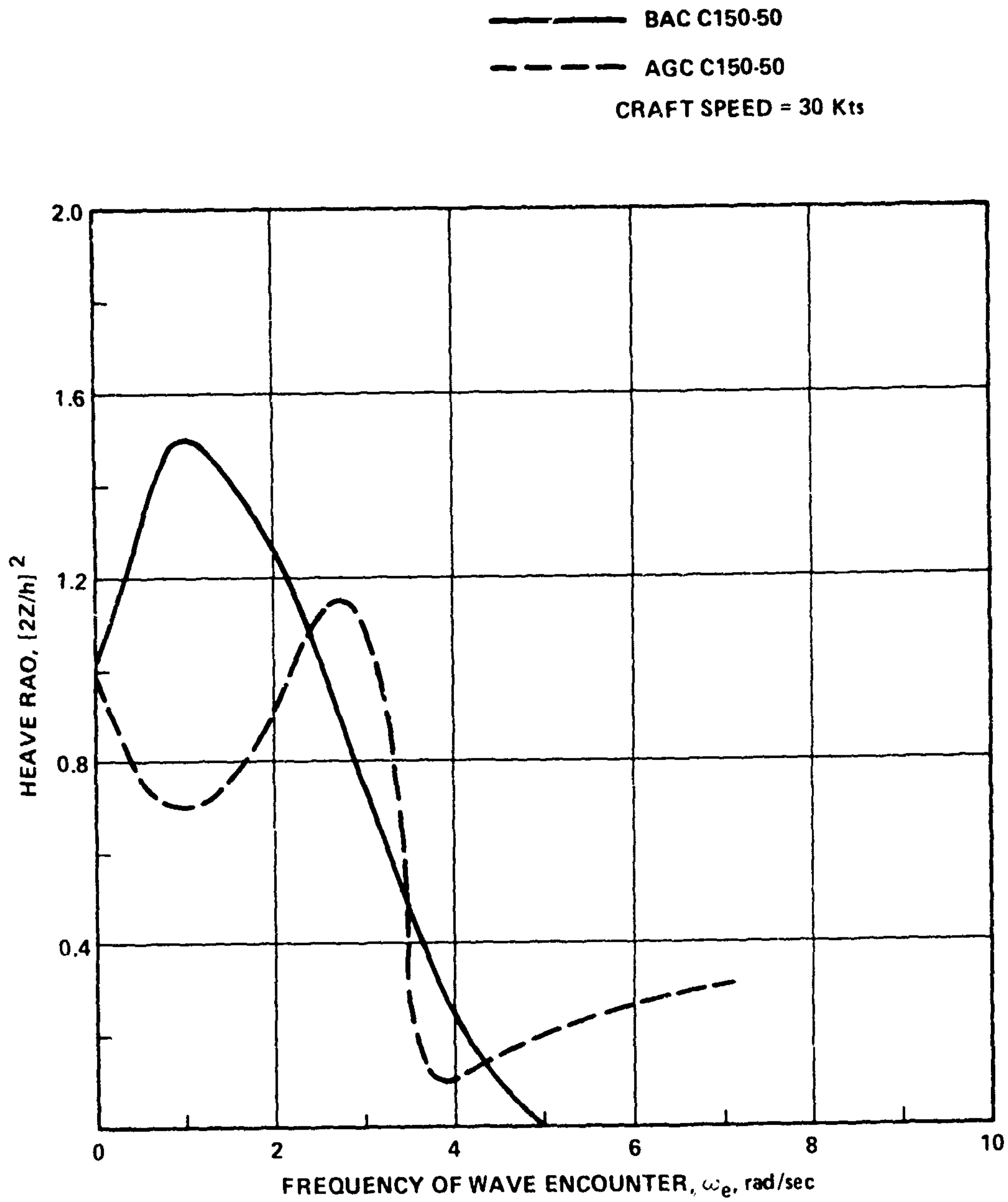

Figure 28a - Results from Experiments in Sea State 3

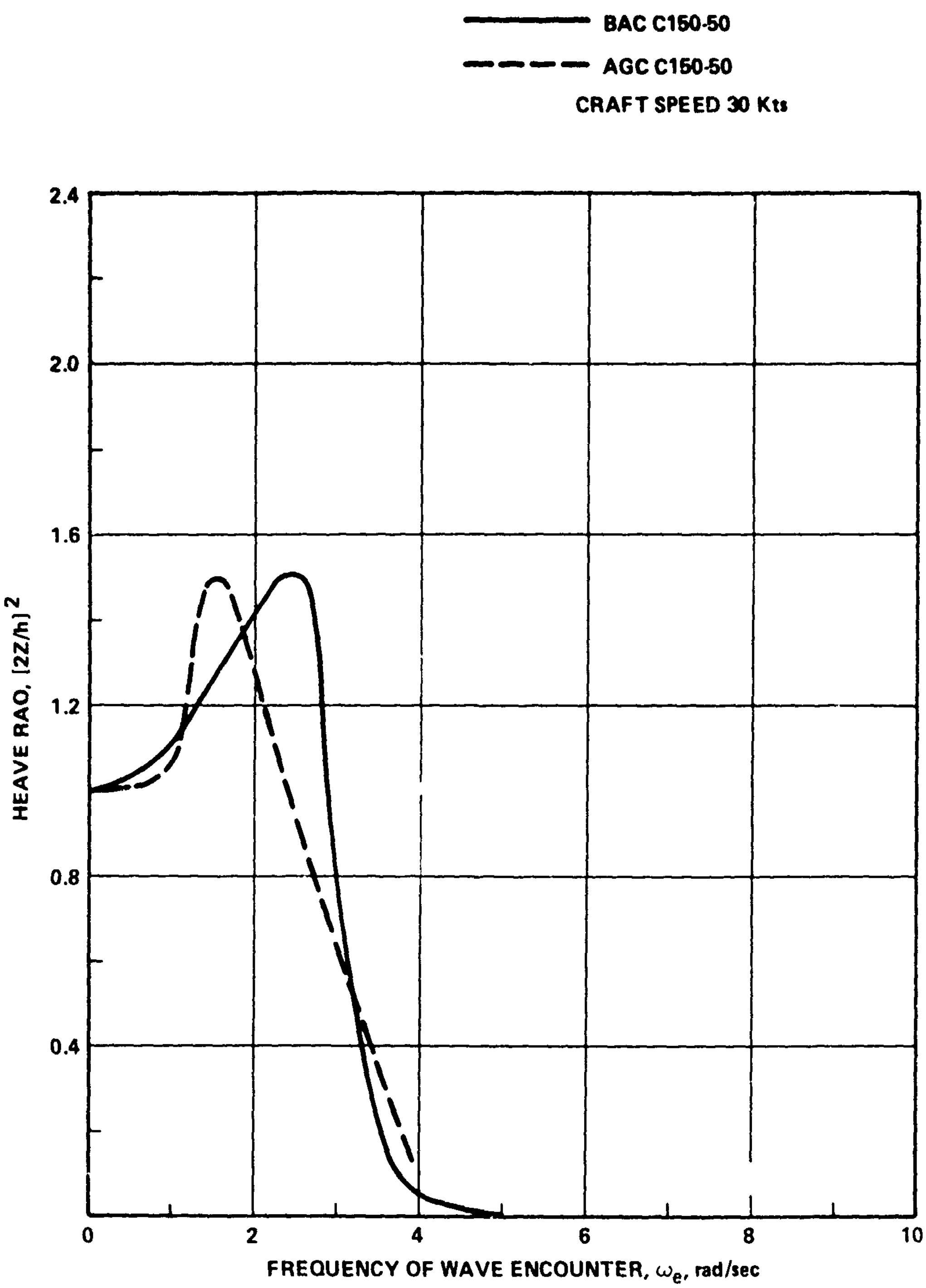

Figure 28b - Results from Experiments in Sea State 4

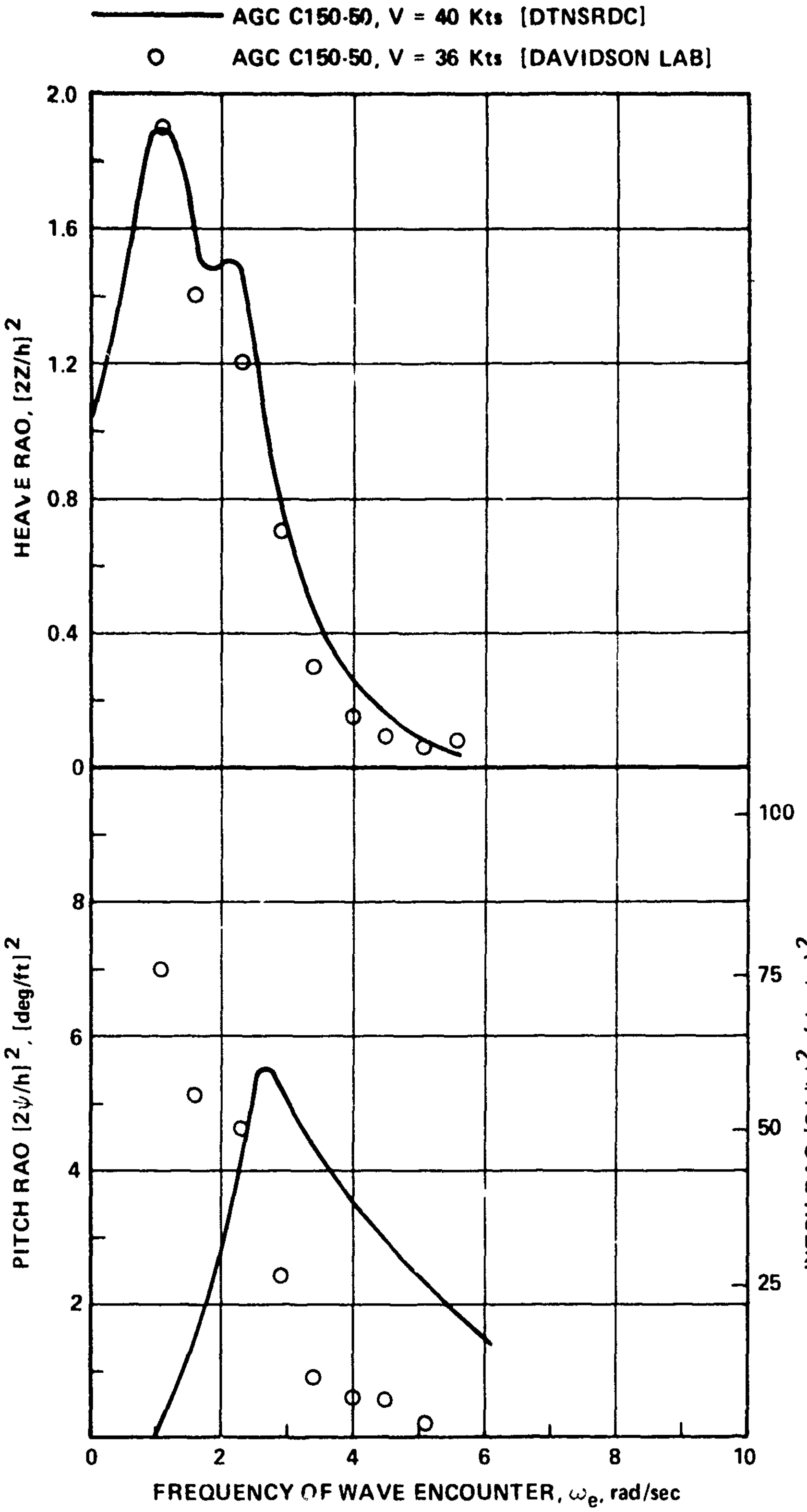

Figure 29 - Heave and Pitch Response Amplitude Operators for the AGC C150-50 Verification Model as Obtained at DTNSRDC and the Davidson Laboratory

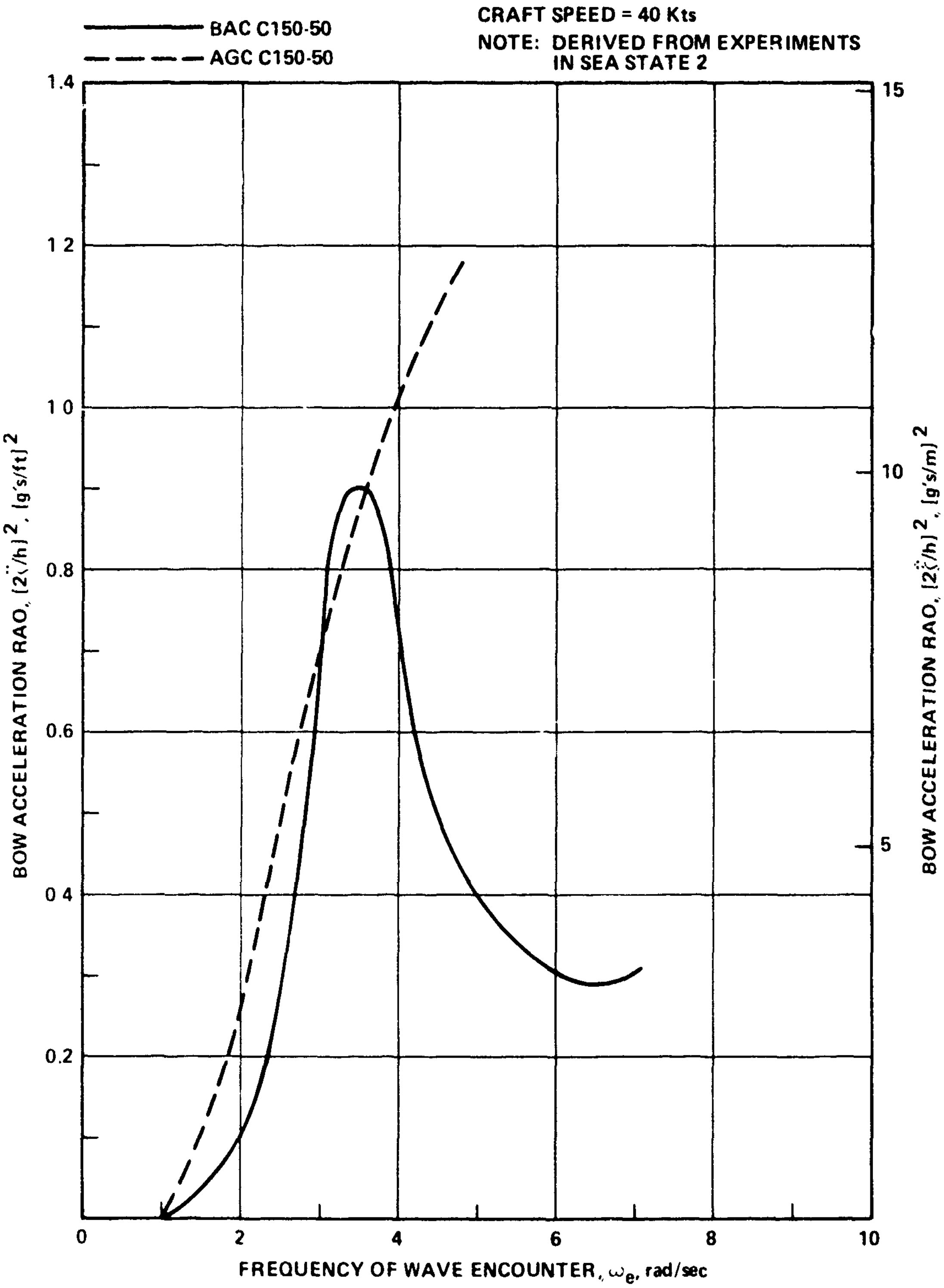

Figure 30 - Bow Acceleration Response Amplitude Operators for the BAC and AGC C150-50 Verification Models at a Speed of 40 Knots

Figure 31 - Bow Acceleration Response Amplitude Operators for the BAC and AGC C150-50 Verification Models at a Speed of 30 Knots

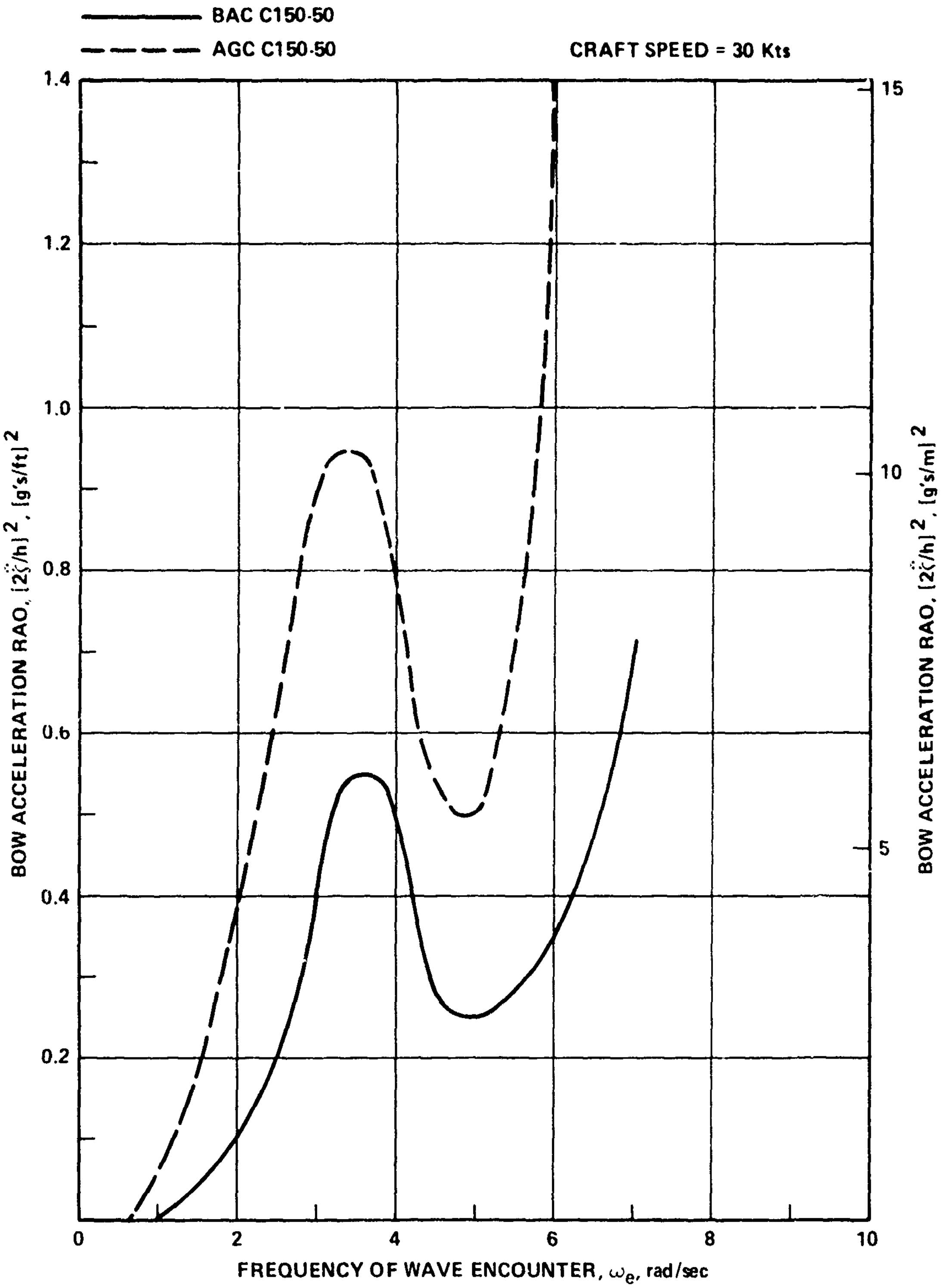

Figure 31a - Results From Experiments in Sea State 3

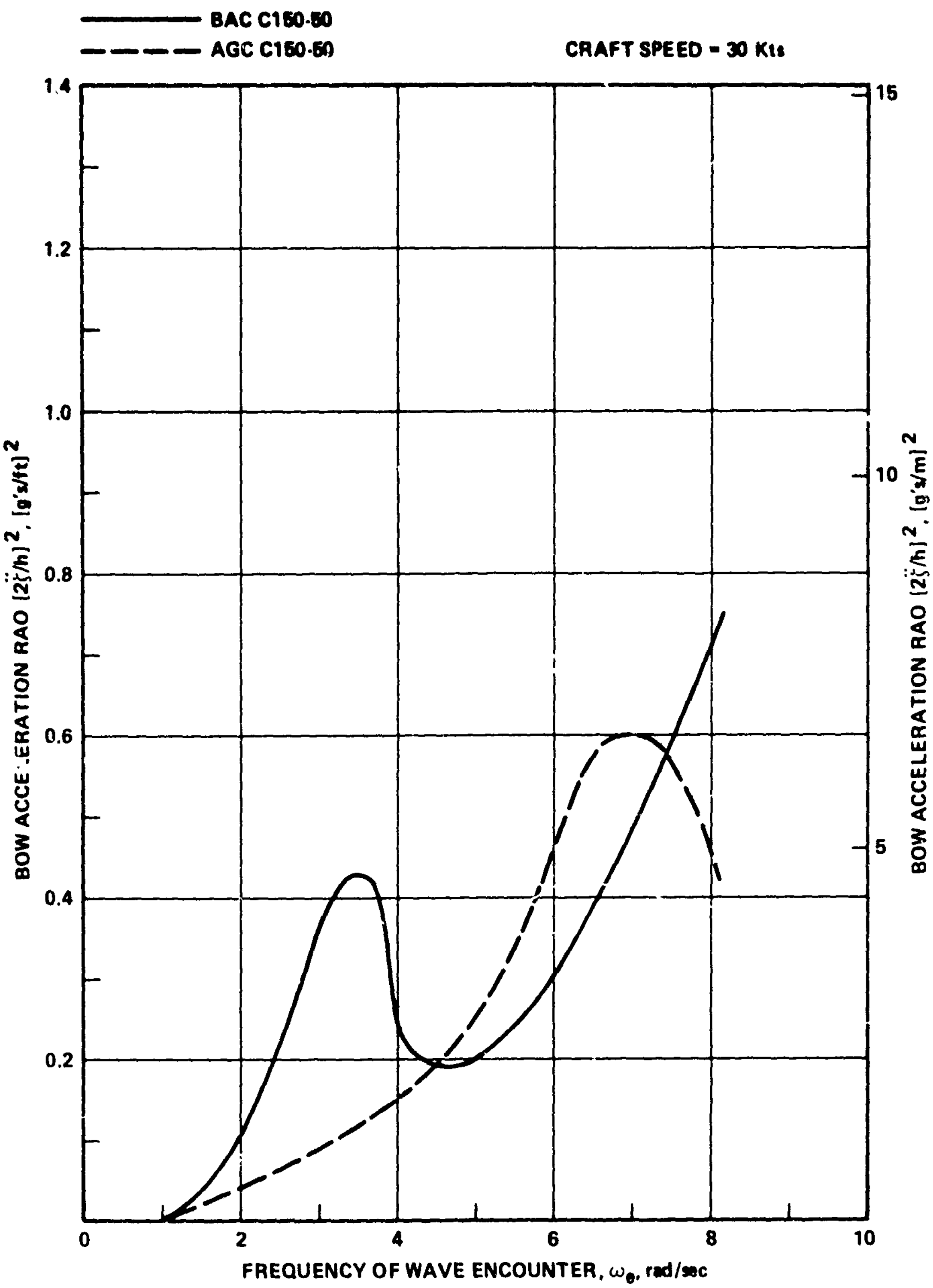

Figure 31b - Results from Experiments in Sea State 4

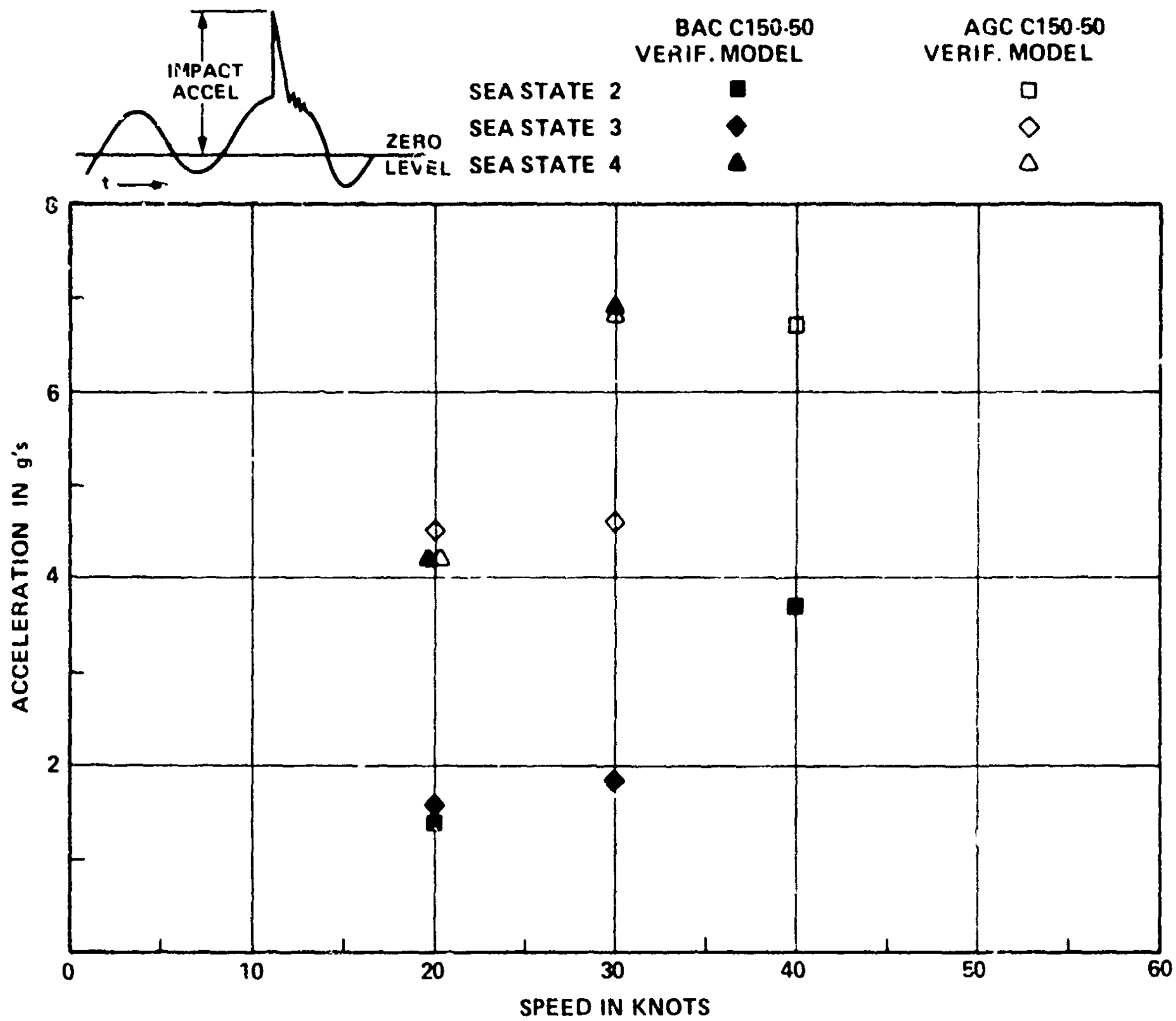

Figure 32 - Maximum Bow Impact Acceleration for the BAC and AGC C150-50 Verification Models

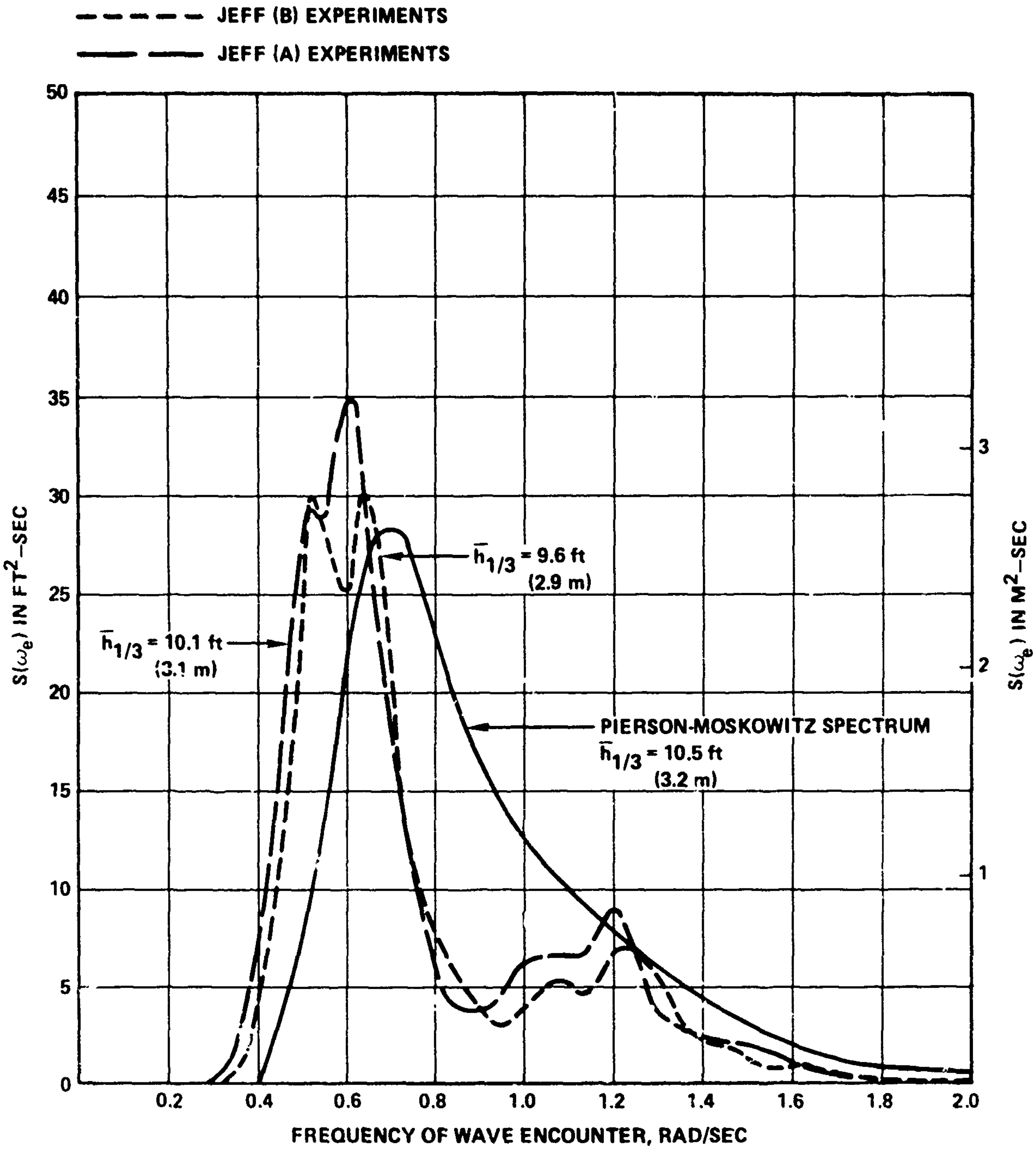

Figure 33 - Typical Wave Spectra for Intact and Damaged Stability Experiments

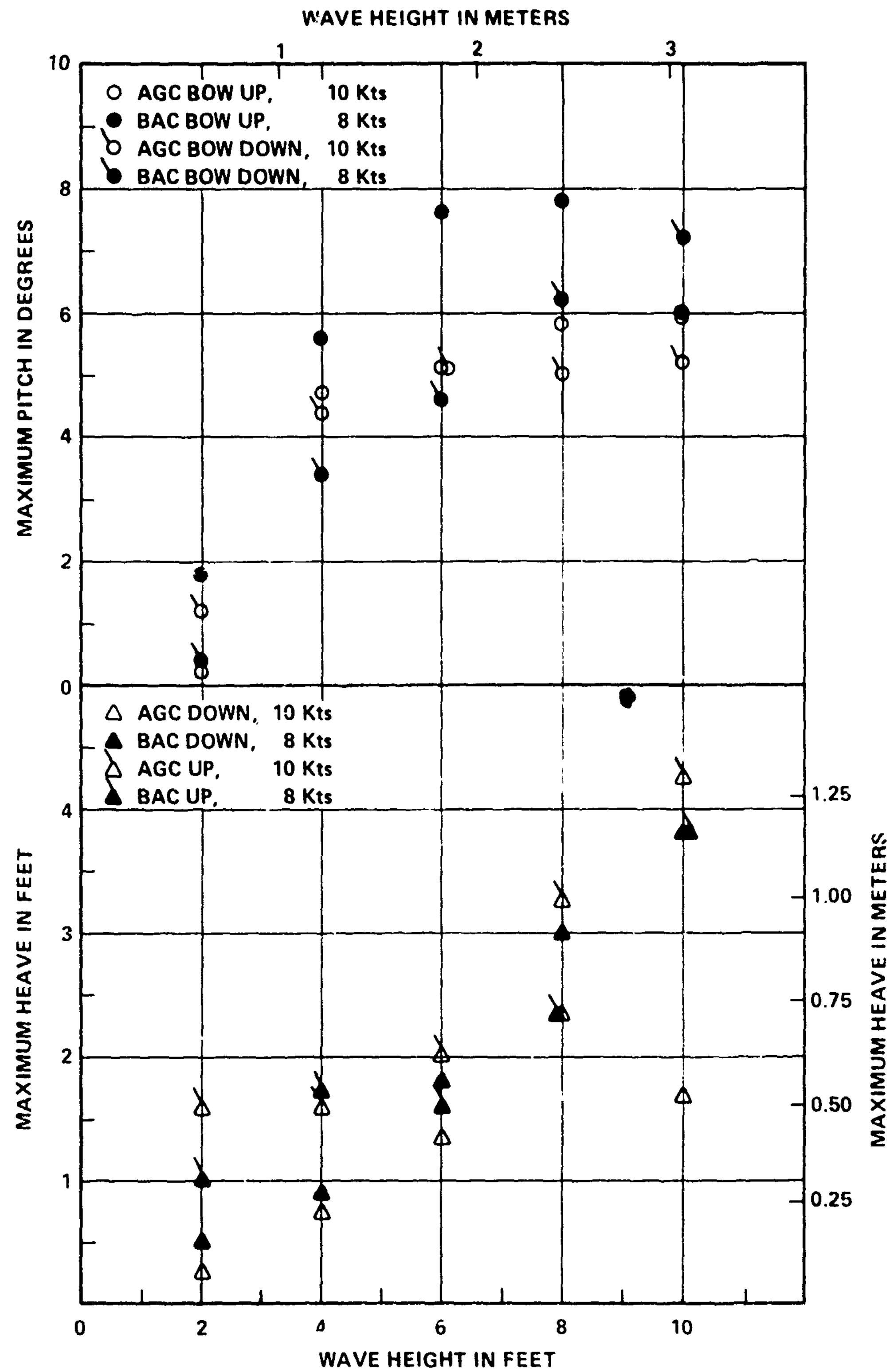

Figure 34 - Maximum Pitch and Heave for the BAC and AGC C150-50 Verification Models While Retracting Through Surf at Sub-Hump Speed

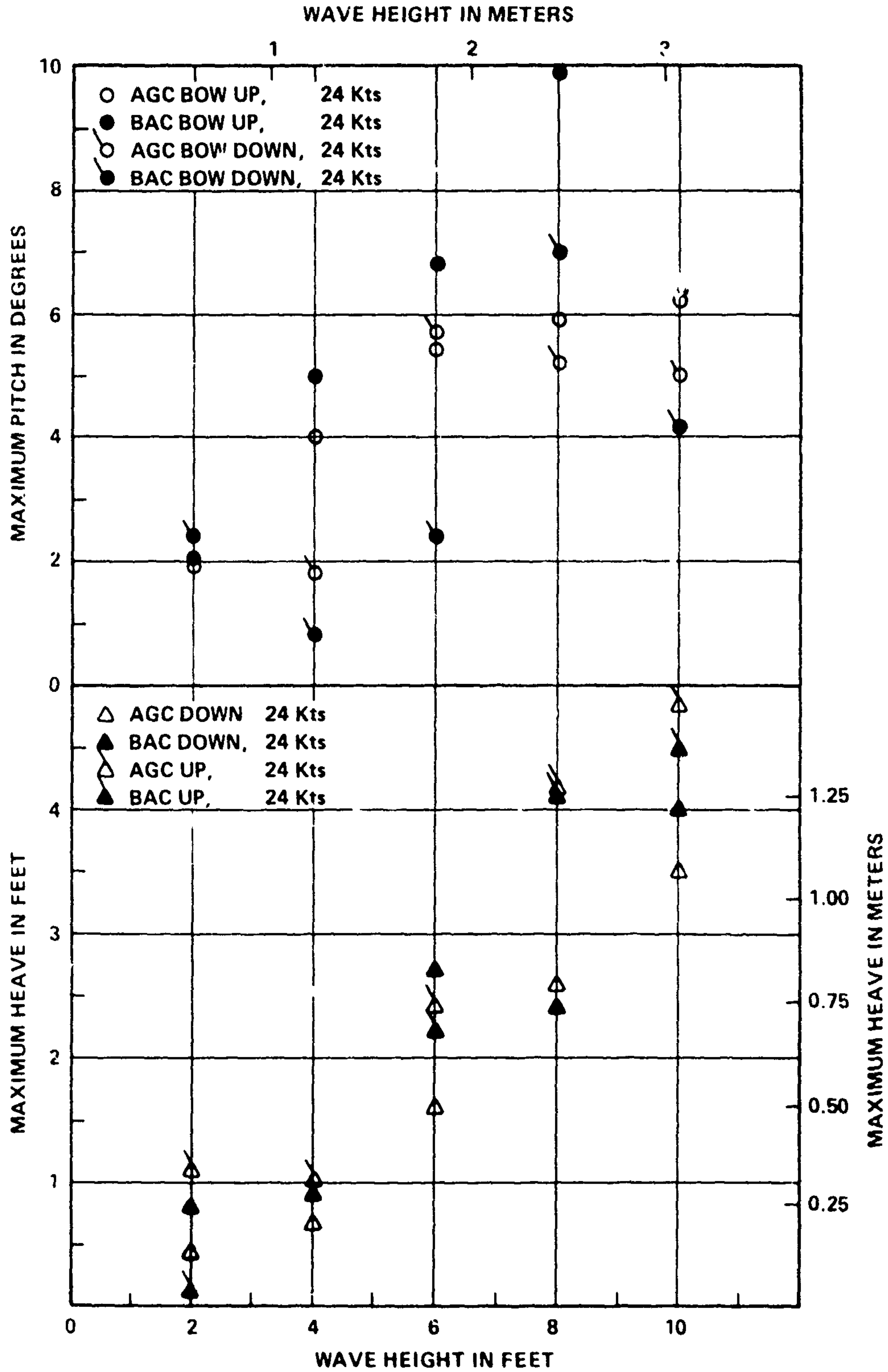

Figure 35 - Maximum Pitch and Heave for the BAC and AGC C150-50 Verification Models While Retracting Through Surf at Post-Hump Speed

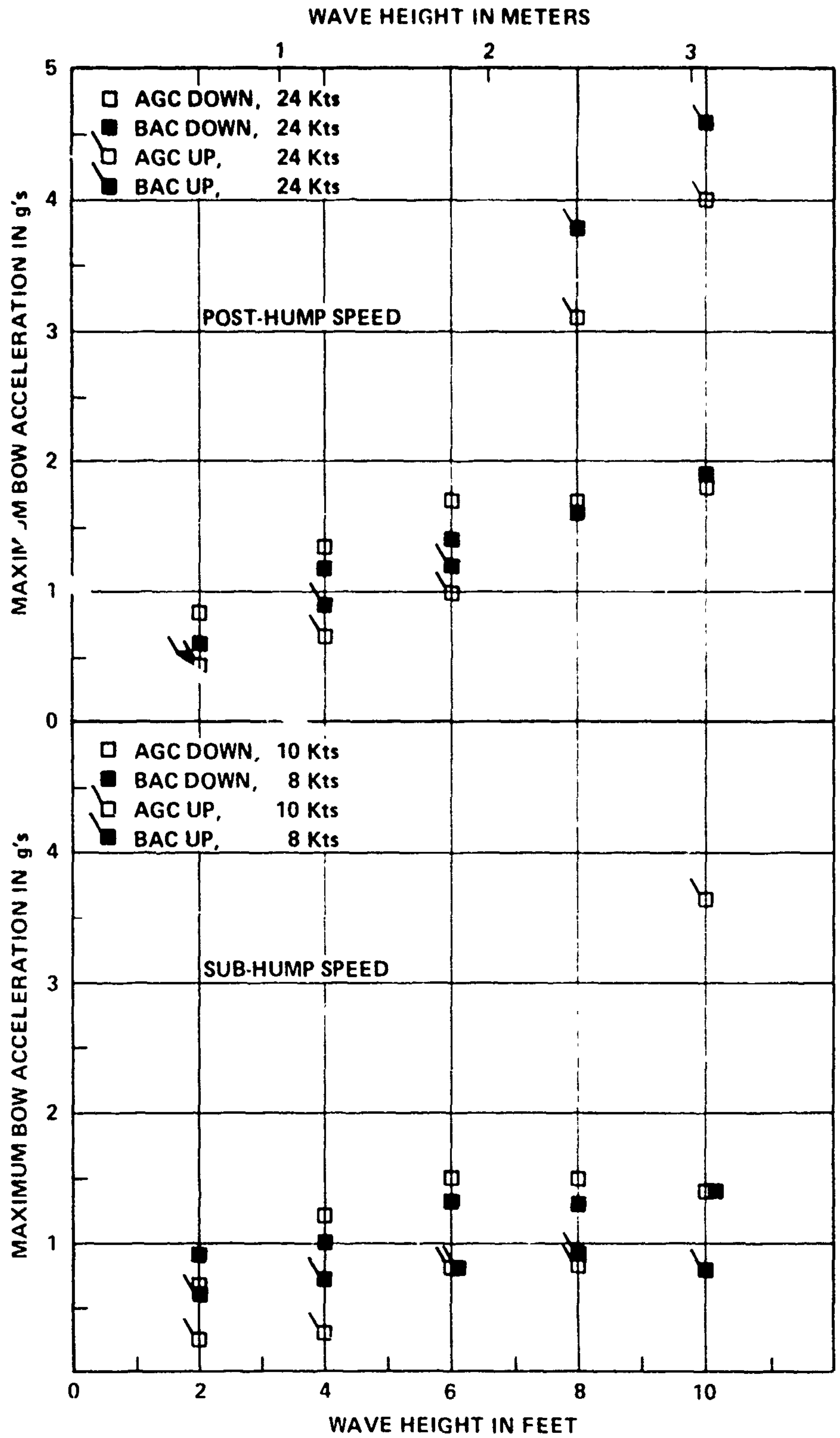

Figure 36 - Maximum Bow Acceleration for the BAC and AGC C150-50 Verification Models While Retracting Through Surf at Sub-Hump and Post-Hump Speeds

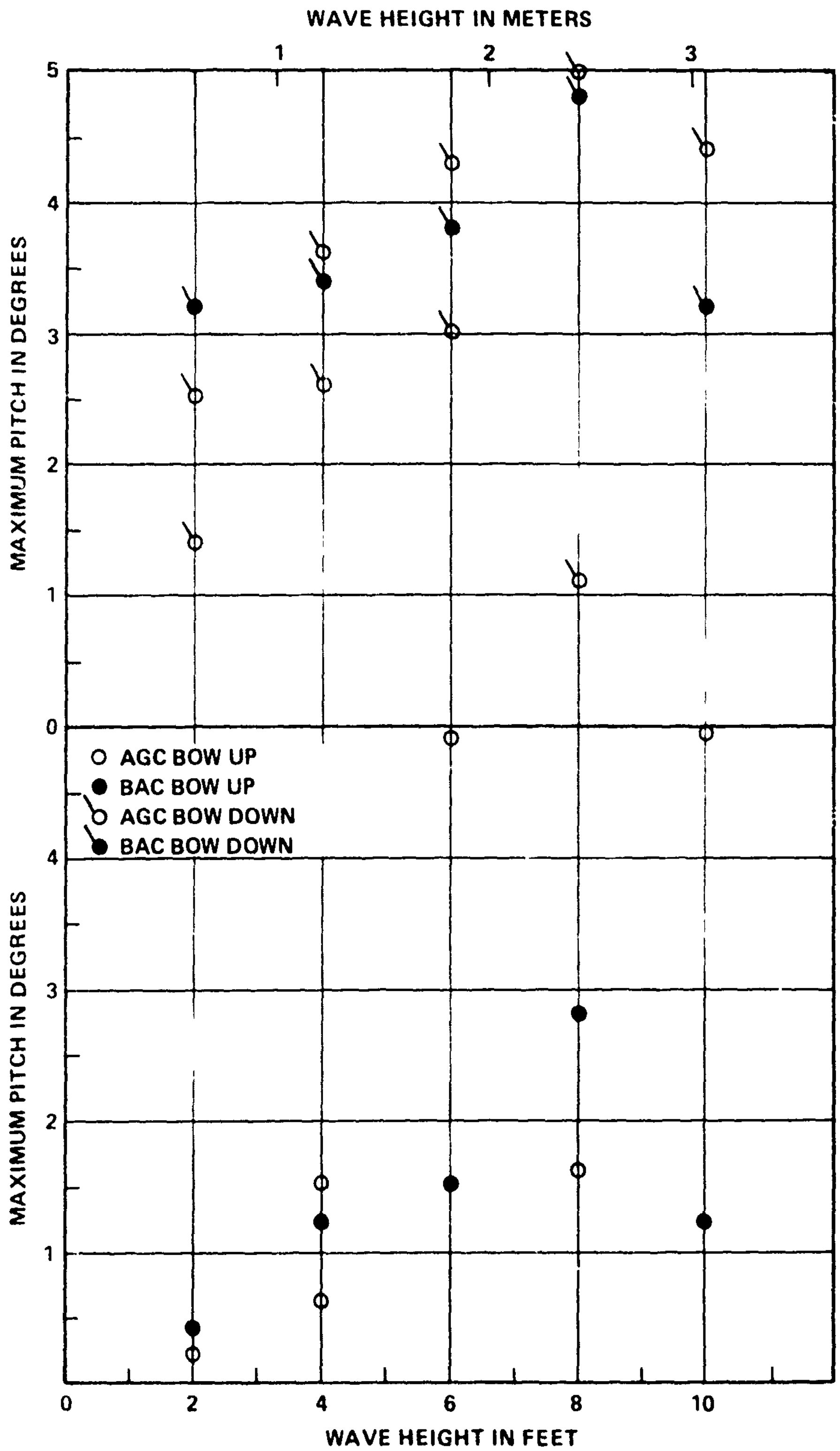

Figure 37 - Maximum Pitch for the BAC and AGC C150-50 Verification Models While Beaching in Surf at Wave Speed

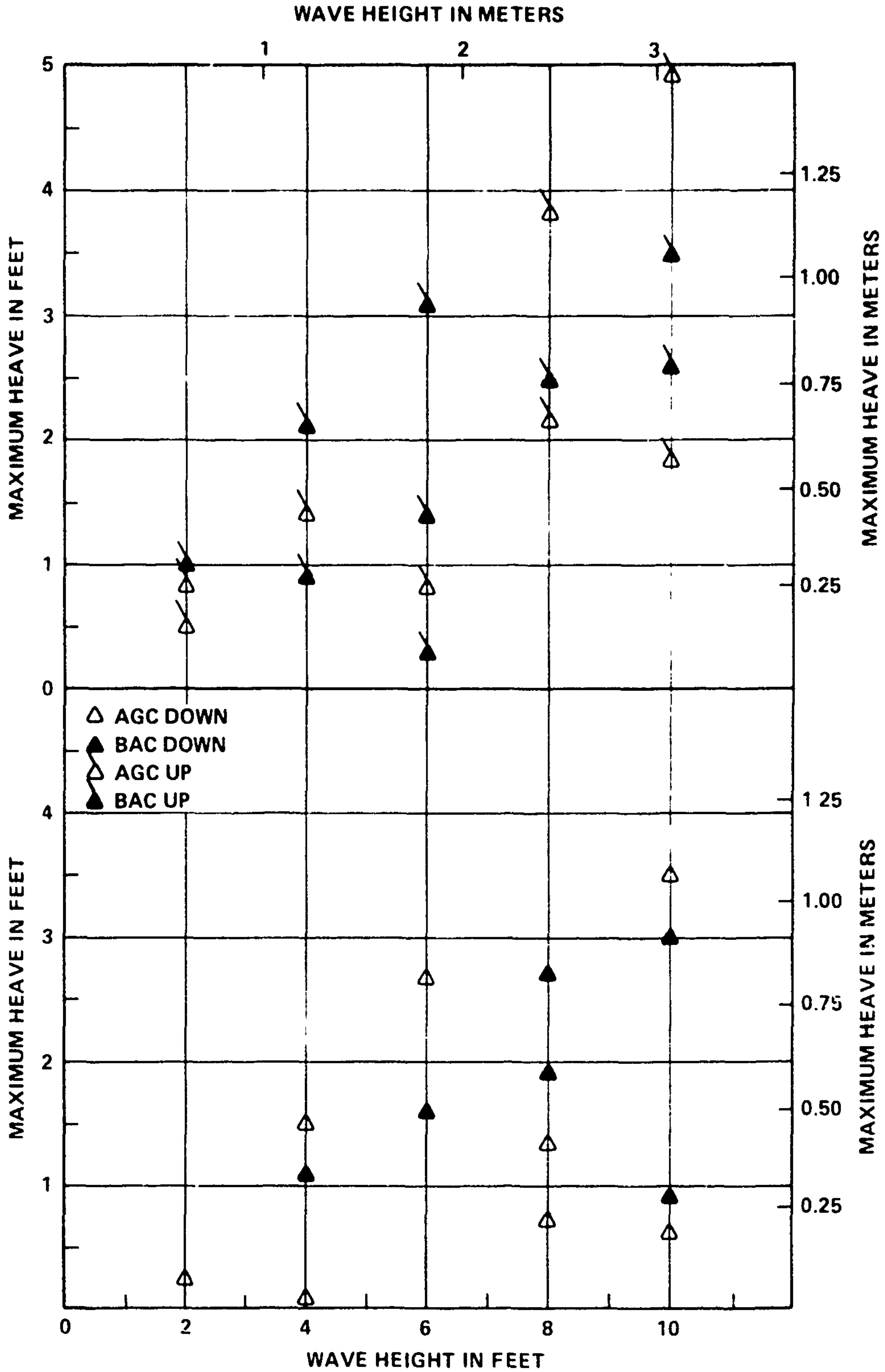

Figure 38 - Maximum Heave for the BAC and AGC C150-50 Verification Models While Beaching in Surf at Wave Speed

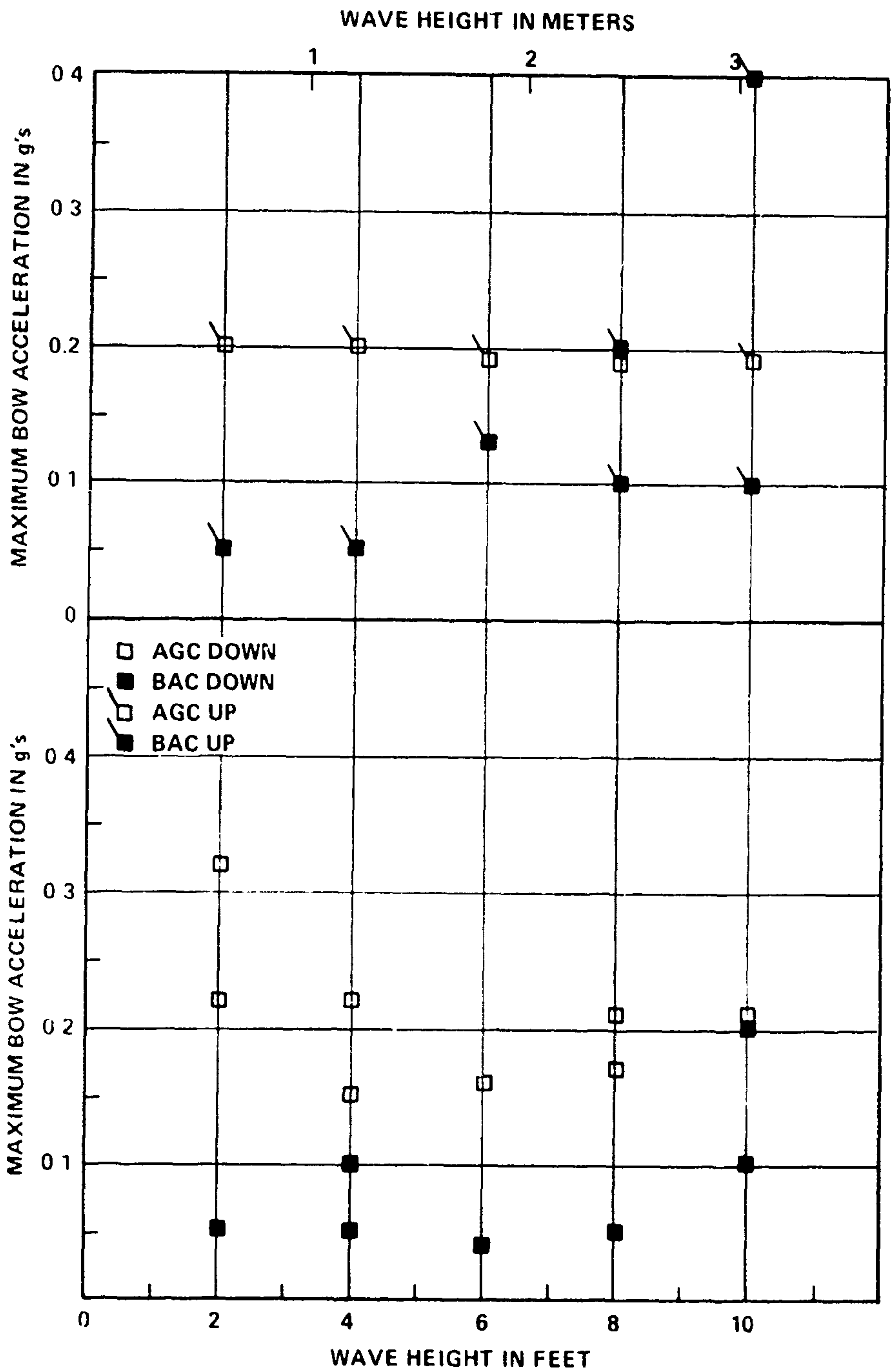

Figure 39 - Maximum Bow Acceleration for the BAC and AGC C150-50 Verification Models While Beaching in Surf at Wave Speed

TABLE 1

CHARACTERISTICS OF MODELS PROVIDED BY AGC AND BAC

		AGC MODEL 104 A *	AGC C150 50 VERIFICATION MODEL (B)	BAC C150 50 VERIFICATION MODEL (B 17) (B)	AGC DER MODEL OF JEFF (A) [3] †	BAC DER MODEL (B 17A) OF JEFF (B) [4]	AGC C150 50 VERIFICATION MODEL [1]	AGC JEFF (A) VERIFICATION MODEL [6]	AGC C150 50 VERIFICATION MODEL [11]	BAC C150 50 VERIFICATION MODEL (B 17) [12]	AGC JEFF (A) VERIFICATION MODEL (C)	BAC JEFF (B) B 17A MODEL (C)
GROSS WEIGHT	lb	320 000 to 335 200	337 000	325 000	333 000	325 000	338 330 to 334 064	332 945	337 100	325 037	333 000	325 000
	kg	145 152 to 152 047	152 863	147 420	151 049	147 420	153 467 to 151 531	151 024	152 909	147 437	151 049	147 420
CG LOCATION	ft	48 6 Fwd Transom	44 8 Fwd Transom	39 6 Fwd Transom	LCG Optimum for SS2		Varied		46 7 Fwd Transom	39 0 Fwd Transom	At Reference Point	At Reference Point
	m	14 8 Fwd Trans	13 7 Fwd Trans	12 1 Fwd Trans					14 05 Fwd Trans	11 9 Fwd Trans		
APPLIED PITCH MOMENT	in lb	None	50 MS About Pt 33 in Fwd of Transom	65 5 MS Bow Down for Level Hover				170 0 MS Bow Up	None	None	None	None
	cm kg		57 6 MS About Pt 83 8 cm Fwd of Transom	75 5 MS Bow Down for Level Hover				195 9 MS Bow Up				
FAN RPM		3 900 MS	8 600 MS	4 330 MS	15 000	1 748	8 500 and 8 600 MS	3 950 MS	8 600 MS	4 330 MS	Fans Off	Fans Off
TOWING POSITION	ft	27 7 Fwd CG	46 7 Fwd Transom	41 5 Fwd Transom					9 0 Above Deck	7 5 Above Deck	Model Not Towed	Model Not Towed
	m	8 4 Fwd CG	14 23 Fwd Transom	12 65 Fwd Transom					2 74 Above Deck	2 3 Above Deck		
PITCH MOMENT OF INERTIA	ft lb sec^2	7 69 x 10^6	5 52 x 10^6	4 37 x 10^6							4 8 x 10^6	4 4 x 10^6
	kg m^2	1 04 x 10^7	7 48 x 10^6	5 93 x 10^6							6 5 x 10^6	5 97 x 10^6
WAVE CONDITIONS	ft	SS2 $h_{1/3}$ - 2 2 SS4 $h_{1/3}$ - 5 7 SS5 $h_{1/3}$ 10 7	SS2 $h_{1/3}$ - 2 2 SS3 $h_{1/3}$ 3 3 SS4 $h_{1/3}$ 6 1	SS2 $h_{1/3}$ - 2 2 SS3 $h_{1/3}$ 3 3 SS4 $h_{1/3}$ 6 1			SS2 $h_{1/3}$ 2 2 SS4 $h_{1/3}$ 6 8				SS5 $h_{1/3}$ 10 1	SS5 $h_{1/3}$ - 9 6
	m	SS2 $h_{1/3}$ - 8 SS4 $h_{1/3}$ 1 7 SS5 $h_{1/3}$ - 3 3	SS2 $h_{1/3}$ 7 SS3 $h_{1/3}$ 1 0 SS4 $h_{1/3}$ - 1 9	SS2 $h_{1/3}$ 7 SS3 $h_{1/3}$ 1 0 SS4 $h_{1/3}$ 1 9			SS2 $h_{1/3}$ 7 SS4 $h_{1/3}$ 2 1				SS5 $h_{1/3}$ 3 1	SS5 $h_{1/3}$ - 2 9
SCALE RATIO		1 15 8	1 16	1 12	1 100	1 12	1 16	1 100	1 16	1 12	1 100	1 12
WIND SPEED	kts	0	0	0	25	0 and 25	0	0	0	0	0	0

* A - SEE FOOTNOTE PAGE 5
B SEE FIRST FOOTNOTE PAGE 6
C SEE FOOTNOTE PAGE 15
† NUMBERS IN BRACKETS REFER TO REFERENCES ON PAGE 20

TABLE 2

SIGNIFICANT DOUBLE AMPLITUDES OF MOTIONS FOR JEFF(A) AND JEFF(B) FROM INTACT AND DAMAGED STABILITY EXPERIMENTS

CONDITION	CRAFT	ROLL, DEG	PITCH, DEG	HEAVE ACCELERATION, g's
BEAM SEA	JEFF (A)	12.3	1.0	0.17
	JEFF (B)	13.7	1.1	0.17
FOLLOWING SEA	JEFF (A)	1.2	8.2	0.12
	JEFF (B)	1.3	9.1	0.13
STERN QUARTER SEA	JEFF (A)	7.2	5.2	0.14
	JEFF (B)	8.7	6.0	0.17
BEAM SEA 2.5° LIST TOWARD SEA	JEFF (A)	11.9	0.9	0.17
	JEFF (B)	13.7	1.2	0.17
BEAM SEA 2.5° LIST FROM SEA	JEFF (A)	11.7	1.0	0.17
	JEFF (B)	14.3	1.3	0.16
STERN QUARTER SEA 2.5° LIST TOWARD SEA	JEFF (A)	8.6	5.7	0.16
	JEFF (B)	8.5	6.3	0.17

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